IACS Common Structural Rules for Double Hull Oil Tankers, January 2006

Background Document

SECTION 7 – LOADS

NOTE:

- This TB is published to improve the transparency of CSRs and increase the understanding of CSRs in the industry.

- The content of the TB is not to be considered as requirements.

- This TB cannot be used to avoid any requirements in CSRs, and in cases where this TB deviates from the Rules, the Rules have precedence.

- This TB provides the background for the first version (January 2006) of the CSRs, and is not subject to maintenance.

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TABLE OF CONTENTS:

1 INTRODUCTION 4

- 1.1 General 4
- 1.2 Definitions 4

2 STATIC LOAD COMPONENTS 5

- 2.1 Static Hull Girder Loads 5
- 2.2 Local Static Loads 7

3 DYNAMIC LOAD COMPONENTS 9

- 3.1 General 9
- 3.2 Motions 10
- 3.3 Ship Accelerations 11
- 3.4 Dynamic Hull Girder Loads 12
- 3.5 Dynamic Local Loads 13

4 SLOSHING AND IMPACT LOADS 27

- 4.1 General 27
- 4.2 Sloshing Pressure in Tanks 27
- 4.3 Bottom Slamming Loads 28
- 4.4 Bow Impact loads 29

5 ACCIDENTAL LOADS 31

- 5.1 Flooded Condition 31

6 COMBINATION OF LOADS 32

- 6.1 General 32
- 6.2 Design Load Combination 32
- 6.3 Application of Dynamic Loads 35
- 6.4 Dynamic Load Cases and Dynamic Load Combination Factors for Strength Assessment 39
- 6.5 Dynamic Load Cases and Dynamic Load Combination for Scantling Requirements 46

1 INTRODUCTION

1.1 General

1.1.1 Application

1.1.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

1.2 Definitions

1.2.1 Coordinate system

1.2.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

1.2.2 Sign conventions

1.2.2.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2 STATIC LOAD COMPONENTS

2.1 Static Hull Girder Loads

2.1.1 Permissible hull girder still water bending moment

2.1.1.a The permissible still water bending moments are needed in order to assess the design.

2.1.1.b The Rules give a minimum permissible still water bending moment and its distribution, see *2.1.2*. The designer is however free to specify a larger hull girder bending moment, which will be used as the basis for the strength assessment.

2.1.1.c The minimum permissible still water bending moments are required at the mid-hold position in addition to the bulkhead positions as the still water bending moment curve is not always maximum at the transverse bulkheads.

2.1.1.d The guidance note on hull girder still water bending moment limits is not a rule requirement but is recommended in order to avoid unpleasant surprises at a later stage of the design process due to a change in lightship weight. If the permissible still water bending moment is given by a specific loading condition and the moment increases due to change in lightship weight, then re-assessment of the ship may be required based on the updated permissible hull girder bending moment.

2.1.2 Minimum hull girder still water bending moment

2.1.2.a The minimum Rule hull girder still water bending moment is included in order to ensure that all ships have a certain operational flexibility regardless of conditions included in the loading manual.

2.1.2.b The formulation for the Rule minimum hull girder still water bending moment was developed based on *IACS Unified Requirement 7* and *11*. *IACS UR S7* defines a minimum hull girder section modulus and *IACS UR S11* defines an allowable hull girder stress and a Rule hull girder wave bending moment. By combining the two requirements an expression for the Rule hull girder still water bending moment which satisfies the two criteria can be extracted.

2.1.2.c The exercise described in *2.1.2.b* was done for both hogging and sagging hull girder bending moment. The resulting moments were compared with permissible still water bending moments found in loading manuals for typical double hull tankers with a reasonable number of loading conditions and operational flexibility. While the formulation for the Rule minimum hogging still water bending moment showed good agreement with the permissible hogging moment of the ships, the implicit permissible IACS hull girder still water sagging moment was significantly higher than the maximum sagging moment found from conditions in the mentioned loading manuals.

2.1.2.d The objective of the Rule minimum still water bending moment value is to provide a safety net and not to drive the scantlings. Based on this the Rule minimum still water sagging moment was calibrated by multiplication of 0.85 with the implicit permissible IACS sagging moment.

2.1.2.e The Rule minimum hull girder still water bending moment for harbour operations is taken as 25% higher than the Rule minimum allowable still water bending moment for the seagoing operations to allow for reasonable flexibility during loading and unloading operations. The 25% value was determined based on review of actual at-sea and in-port conditions and discussions with operators.

2.1.2.f Similar to the Rule minimum hull girder still water bending moment the associated still water bending moment distribution given in *Figure 7.2.1 of the Rules* will ensure that the ship has a reasonable amount of operational flexibility.

2.1.3 Still water shear force

2.1.3.a The permissible hull girder still water shear forces are needed in order to assess the design.

2.1.3.b The permissible hull girder shear force limits are required given in the mid-hold position in addition to the bulkhead position in order to provide the envelope curve and to be able to assess the extent of local strengthening of longitudinal bulkheads towards transverse bulkheads.

2.1.3.c The guidance note related to hull girder shear force limits is not a rule requirement but is recommended in order to avoid unpleasant surprises at the later stage of the design process due to change in lightship weight. If the permissible still water shear force is given by a specific loading condition and the shear force increases due to change in lightship weight or draught re-assessment of the ship may be required based on the updated permissible still water shear force.

2.1.4 Minimum hull girder still water shear force

2.1.4.a The minimum Rule hull girder still water shear force is included to ensure that all ships have a certain operational flexibility regardless of conditions included in the loading manual.

2.1.4.b The formulae represent the local shear force that is generated by the difference of cargo weight, steel weight and buoyancy between adjacent holds.

2.1.4.c The hull girder steel weight between transverse bulkheads is expressed as:

$$W_{steel-weight} = 0.1 \rho g B_{local} l_{tk} T_{sc} \quad \text{kN}$$

Where:

ρ	density of cargo/sea water, not to be taken less than 1.025 tonnes/m^3
g	acceleration due to gravity, 9.81 m/s^2
B_{local}	local breadth at T_{sc} at the middle length of the tank under consideration, in m
l_{tk}	length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m
T_{sc}	scantling draught, in m, as defined in *Section 4/1.1.5.5* of the Rules

This simplification has through verification on typical tankers ranging from product carriers to VLCC's shown to be representative for the actual steel weight.

2.1.4.d The formulations of the minimum positive and negative still water shear force are consistent with the Rule loading conditions specified for the Finite Element analysis in *Appendix B/Table B.2.3 and B.2.4* of the Rules.

2.1.4.e The minimum values given in *Section 7/2.1.4* of the Rules apply in way of the transverse bulkheads between cargo tanks. For other positions the hull girder shear force is to be as given by *Section 7/2.1.3.5* and *2.1.3.6* of the Rules.

2.2 Local Static Loads

2.2.1 General

2.2.1.a The local loads considered are:

(a) static sea pressures
(b) static tank pressure
(c) tank overpressure
(d) static deck loads from stores and equipment

2.2.2 Static sea pressure

2.2.2.a The static sea pressure is taken as the hydrostatic pressure head due to gravity. The hydrostatic pressure resulting from inclination of the ship due to rolling motion is taken into account as a quasi-static term in the expression of the dynamic wave pressure.

2.2.3 Static tank pressure

2.2.3.a The static tank pressure has different terms which are applicable for different load scenarios and tank types. These are divided into different pressure components as shown in *Table 7.2.a*.

2.2.4 Static deck pressure from distributed loading

2.2.4.a The loading is taken to be uniformly distributed and expressions for the pressures are derived from the loads and the projected loaded area.

2.2.5 Static loads from heavy units

2.2.5.a The static force due to heavy unit loads is taken as the gravitational force of the load.

Table 7.2.a
Static Tank Pressures and Overpressures

Pressure	**Description**
P_{in-tk}	The static pressure in a tank due to liquid filling. The pressure assumes that the tank is 100% full and is measured from the highest point in the tank.
P_{in-air}	As above but only applicable for ballast tanks and other tanks where the tank can/will be over-filled. The pressure is measured from the top of the air-pipe or from the top of any possible over-flow. This condition is typical for tank filling during flow-through for Ballast Water Exchange at sea and harbour conditions.
P_{drop}	The increase in pressure due to resistance in the air-pipe during pumping operation. It is taken to be 25kN/m^2 for ballast tanks and zero for other tanks. If the actual pressure drop is available this should be used instead of the minimum value of 25kN/m^2 if it is greater.
$P_{in-flood}$	Takes into account the design pressure on a flooded watertight bulkhead. The load point is measured from the deepest equilibrium waterline in the damaged condition obtained from applicable damage stability calculations.
$P_{in-test}$	Tank pressure during structural testing, see also *Section 2/Table 2.5.1* of the Rules and *Section 11/Table 11.5.1* of the Rules.
P_{valve}	Setting of pressure relief valve. Cargo tanks are fitted with pressure relief valves. The minimum value is to be taken as 25kN/m^2, used during structural testing purpose. P_{valve} is only applicable for tanks which are fitted with pressure relief valves; hence it is not applicable for e.g. segregated ballast tanks.

3 DYNAMIC LOAD COMPONENTS

3.1 General

3.1.1 Basic components

3.1.1.a The basis for the dynamic loads is the standard long term statistical prediction and includes the application of:

(a) a representation of the North Atlantic wave environment. The applied detailed wave-scatter diagram and short-term and long-term statistical prediction approach is given in IACS Rec. 34;

(b) the Pierson-Moskowitz wave spectrum;

(c) a wave energy-spreading of $\cos^2$;

(d) an equal probability on all wave headings;

(e) 3-D linear hydrodynamic calculations, with a 30 degree step of ship/wave heading.

3.1.2 Envelope load values

3.1.2.a The value of the loads is determined by hydrodynamic direct calculations using selected loading conditions and speeds. The speed and loading condition are chosen based on the corresponding application of load and the structural assessment method. Thus, for:

(a) strength evaluation; a heavy ballast condition and a full load condition at scantling draught have been used for the assessment, applying no forward speed, as tankers are full-form ships with negligible manoeuvring speed in heavy weather due to voluntary and involuntary reasons;

(b) fatigue assessment; normal ballast and full load condition at design draught have been evaluated as the two most common sailing conditions. A speed of 75% of service speed has been taken as the average speed over the lifetime, taking into account effects of slamming, bow submergence, added wave resistance and voluntary speed reduction.

3.1.2.b The probability of occurrence is tailored to the purpose of application of the load and the selected structural assessment method is to be as follows:

(a) The loads for fatigue assessment are based on a probability of exceedance of 10^{-4}. The probability level gives loads which occur frequently. The 10^{-4} is the reference probability level that together with a Weibull shape parameter and average zero-crossing period define the expected load history.

(b) The loads for strength evaluation are based on a probability of exceedance of 10^{-8}. The probability level represents the expected maximum load during the design life.

3.1.2.c General formulae for linear wave induced ship motion, acceleration, hull girder loads and wave pressures are given at both 10^{-8} and 10^{-4} probability levels.

3.1.2.d For scantling requirements and strength assessment, correction factors to account for non-linear wave effects are applied to the linear loads. In beam sea condition for evaluation a correction factor to account for operational considerations are applied to the linear loads.

3.1.2.e Correction factors to account for speed effects are applied to the linear loads for fatigue assessment. Also adjustment factors to adjust from 10^{-8} to 10^{-4} are applied.

3.1.3 Metacentric height and roll radius of gyration

3.1.3.a Typical values for GM, the transverse metacentric height, and $r_{roll-gyr}$ are provided. The values for GM are approximated based on information in the Loading Manuals of typical loading conditions for tankers. The values for $r_{roll-gyr}$ are based on typical loading conditions for tankers.

3.2 Motions

3.2.1 General

3.2.1.a The roll and pitch motions are provided at the 10^{-8} probability level only.

3.2.1.b For the pitch-period, a speed effect is included for fatigue assessment. The pitch period is used when determining the accelerations.

3.2.2 Roll motion

3.2.2.a The roll period U_{roll} is given to represent the roll natural period, and is based on simple physical relations. The added mass effect is taken into account by the factor 2.3 instead of 2.

3.2.2.b The roll amplitude θ is the roll-angle envelope with a 10^{-8} probability of exceedance. θ considers the influence of roll period, as well as the effect of bilge keels, the mass-distribution and the GM on the roll period.

3.2.2.c The roll-angle is dependent on the roll natural period U_{roll} and coupled to the mean period of the wave-scatter diagram. The formulation is correlated to the roll natural period, based on considerations of wave energy/wave period versus ship roll period.

3.2.3 Pitch motion

3.2.3.a The pitch period U_{pitch} is the characteristic period of the ship, i.e. the peak of the RAO (Response Amplitude Operator which indicates the motion at a given wave period) in head sea.

3.2.3.b U_{pitch} is mainly proportional to $\sqrt{L}$, but is also affected by the loading condition. This is accounted for by f_T, which is the ratio between the draught of loading condition in question and the scantling draught.

3.2.3.c The pitch period is dependent on the main wave periods in head sea and is strongly linked to the encounter period, and thus the ship-speed will influence the characteristic pitch period. The pitch period will decrease for increasing ship speed.

3.2.3.d The pitch angle is given to represent the envelope pitch-angle with a 10^{-8} probability of exceedance.

3.3 Ship Accelerations

3.3.1 General

3.3.1.a Expressions for accelerations along body-fixed x-axis (longitudinal), y-axis (transverse) and z-axis (vertical) are given. The accelerations are combinations of the basic rigid body global motion accelerations in all six degrees of freedom, where each component is assumed to be independent, but factors to account for phase-differences between the acceleration components are included. The yaw acceleration is not explicitly given.

3.3.2 Common acceleration parameter

3.3.2.a a_0 is a basic vertical acceleration parameter representing heave, sway, yaw and surge motion.

3.3.3 Vertical acceleration

3.3.3.a The vertical acceleration, a_v, is acceleration along the body-fixed z-axis. The general expression predicts vertical acceleration with a 10^{-8} probability of exceedance anywhere on the ship (assuming both f_V and f_{prob} equal 1.0). a_v includes heave, pitch and roll components. The motion reference point is assumed to be at the centreline and $0.45L$ from aft end of L.

3.3.3.b The vertical acceleration due to roll motion, a_{roll-z}, is multiplied by a factor of 1.2 to account for the phase difference between roll acceleration and the combined heave and pitch acceleration. The vertical acceleration due to pitch motions, $a_{pitch-z}$, is multiplied by a factor of $(0.3 + L/325)$ to account for different phase relation between the acceleration components. This phasing is dependent on the ship length.

3.3.3.c The probability factor, f_{prob}, for fatigue, is taken as 0.45, which gives the best fit with direct calculations, and accounts for the difference in probability level for fatigue strength assessment (10^{-4} probability vs. 10^{-8}), and speed effects.

3.3.3.d The vertical acceleration due to heave, expressed by a_{heave}, includes a factor f_V, which accounts for speed effects. f_V is calibrated to make the vertical acceleration in amidships region match the trends between loaded and ballast condition found in the direct calculations for the loads for fatigue strength. The increased pitch vertical acceleration due to forward speed is taken account for by the decreased pitch period, see *3.2.3.c*. The speed effect on pitch-motion is assumed to be negligible when the speed effect on pitch period is taken into account. The speed is assumed to have no influence on the roll vertical acceleration, since roll is a beam sea dominant response, and the encounter frequency in beam sea is not affected by a speed change.

3.3.3.e No other non-linear effects are included for vertical acceleration.

3.3.4 Transverse acceleration

3.3.4.a The transverse acceleration, a_t, is a combination of the contribution from roll, sway and yaw acceleration along the body-fixed y-axis. The general expression predicts the transverse acceleration at a 10^{-8} probability level anywhere on the ship. The transverse acceleration is taken constant over the breadth of ship, assuming that the yaw acceleration component is negligible. The yaw-term is therefore not explicitly given. a_t also includes the g-component of roll.

3.3.4.b The vertical rotational axis, R_{roll}, for the roll acceleration a_{roll-y} is assumed to be the greater of $D/2$ and ($D/4$ + $T_{LC}/2$), which is an approximation of the vertical centre of gravity of the ship.

3.3.4.c The roll and sway transverse accelerations, a_{roll-y} and a_{sway}, are assumed to be statistically independent.

3.3.4.d f_{prob} for fatigue is taken as 0.5 for best fit with direct calculations at a 10^{-4} probability level. This factor accounts for different probability levels.

3.3.4.e The transverse acceleration is assumed to have no speed effects because it is beam seas dominant. No other non-linear effects are included.

3.3.5 Longitudinal acceleration

3.3.5.a The longitudinal acceleration, a_{lng}, is a combination of the contribution from surge, yaw, and pitch acceleration. The general expression predicts the longitudinal acceleration with a 10^{-8} probability of occurrence anywhere on the ship. The longitudinal acceleration is constant along the ships length, assuming that the yaw acceleration component is negligible. The yaw term is therefore not explicitly given. The g-component of the pitch angle is included in the expression.

3.3.5.b The pitch and surge accelerations are assumed to be statistically independent for larger ships. However for shorter ships, the accelerations start cancelling each other. A factor of $L/325$ to account for this is included.

3.3.5.c The vertical rotational axis, R_{pitch}, for $a_{pitch-x}$ is assumed to be the greater of $D/2$ and ($D/4$ + $T_{LC}/2$), which is an approximation of the vertical centre of gravity of the ship.

3.3.5.d f_{prob} for fatigue is taken 0.5 for best fit with direct calculations at the 10^{-4} probability level. This factor takes account for different probability levels.

3.3.5.e The pitch longitudinal acceleration, $a_{pitch-x}$, has a speed factor, f_V.

3.4 Dynamic Hull Girder Loads

3.4.1 Vertical wave bending moment

3.4.1.a The vertical wave bending moment is taken as specified in *IACS URS11*.

3.4.1.b The wave coefficient, C_{wv}, is given as a function of ship length L, and is used in the expressions given for wave pressures and global hull girder wave loads. The C_{wv} values are valid for world wide service and are representative for the North-Atlantic wave statistics.

3.4.1.c The wave induced hull girder vertical bending moment, M_{wv}, is specified as the envelope value at a 10^{-8} probability level. The influence of non-linear wave induced loads on the vertical hull girder bending is taken into account through the following embedded coefficients:

for hogging $\quad \dfrac{1.9C_b}{C_b + 0.7}$

for sagging $\quad -1.1$,

which gives the hogging/sagging ratio of:

$$\frac{M_{wv-hog}}{M_{wv-sag}} = \frac{1.727C_b}{C_b + 0.7}$$

Where:

M_{wv-hog} vertical wave hogging moment

M_{wv-sag} vertical wave sagging moment

C_b block-coefficient, not to be taken less than 0.6

3.4.1.d The influence of slamming and whipping (flare effect) is not included in the non-linear effects, but is assumed to be included within the distribution factor, f_{wv-v}.

3.4.1.e An adjustment factor, f_{prob}, of 0.5 is applied for fatigue assessment, which accounts for:

(a) the probability level;

(b) speed effects, hence, for full load condition, the speed effects are considered small, while for ballast condition the speed effect is greater, which justifies that the same wave vertical bending moment can be used for the two loading conditions;

3.4.1.f For fatigue evaluations, the distribution of the vertical wave bending moment has a knuckle at 0.1*L* and 0.9*L* from A.P. to get a closer fit with direct calculations.

3.4.2 Horizontal wave bending moment

3.4.2.a The wave induced hull girder horizontal bending moment, M_{wv-h}, is specified as the envelope value with a probability level of exceedance of 10^{-8}. M_{wv-h} accounts for different loading conditions by using the draught.

3.4.2.b f_{prob} is taken as 0.5 for fatigue strength. The factor takes the difference in probability level into account and is tuned with direct calculations.

3.4.2.c M_{wv-h} is assumed to have no speed effects because it is an oblique or beam sea dominated response. M_{wv-h} is assumed to have no non-linear effects.

3.4.2.d For fatigue evaluations, the distribution of the horizontal wave bending moment has a knuckle at 0.1*L* and 0.9*L* from A.P. to get a closer fit with direct calculations.

3.4.3 Vertical wave shear force

3.4.3.a The vertical wave shear force is taken as specified in *IACS URS11*, see also *3.4.1*.

3.5 Dynamic Local Loads

3.5.1 General

3.5.1.a It is considered that for this topic, no information in addition to that shown in the Rules, is necessary to explain the background.

3.5.2 Dynamic wave pressure

3.5.2.a The dynamic wave pressure is specified as the envelope value with a probability level of 10^{-8} and 10^{-4}, and is applicable any place on the ship.

3.5.2.b The wave pressure is taken as the greatest pressure resulting from the P_1 and P_2 pressures. The P_1-pressure is dominated by pitch motion in head/quartering seas, while the P_2-pressure is dominated by roll motion in beam seas. P_2 will dominate in the amidships region and P_1 will dominate in forward and aft ends of the ship.

3.5.2.c The wave pressure-formulation accounts for the various dynamic effects; such as ship motions and accelerations (e.g. roll, pitch, and heave), wave excitation, and wave build-up effects.

Figure 7.3.a
Girth wise Distribution of Dynamic Wave Pressure
for Strength Assessment by Prescriptive Rule Requirements and FE Analysis

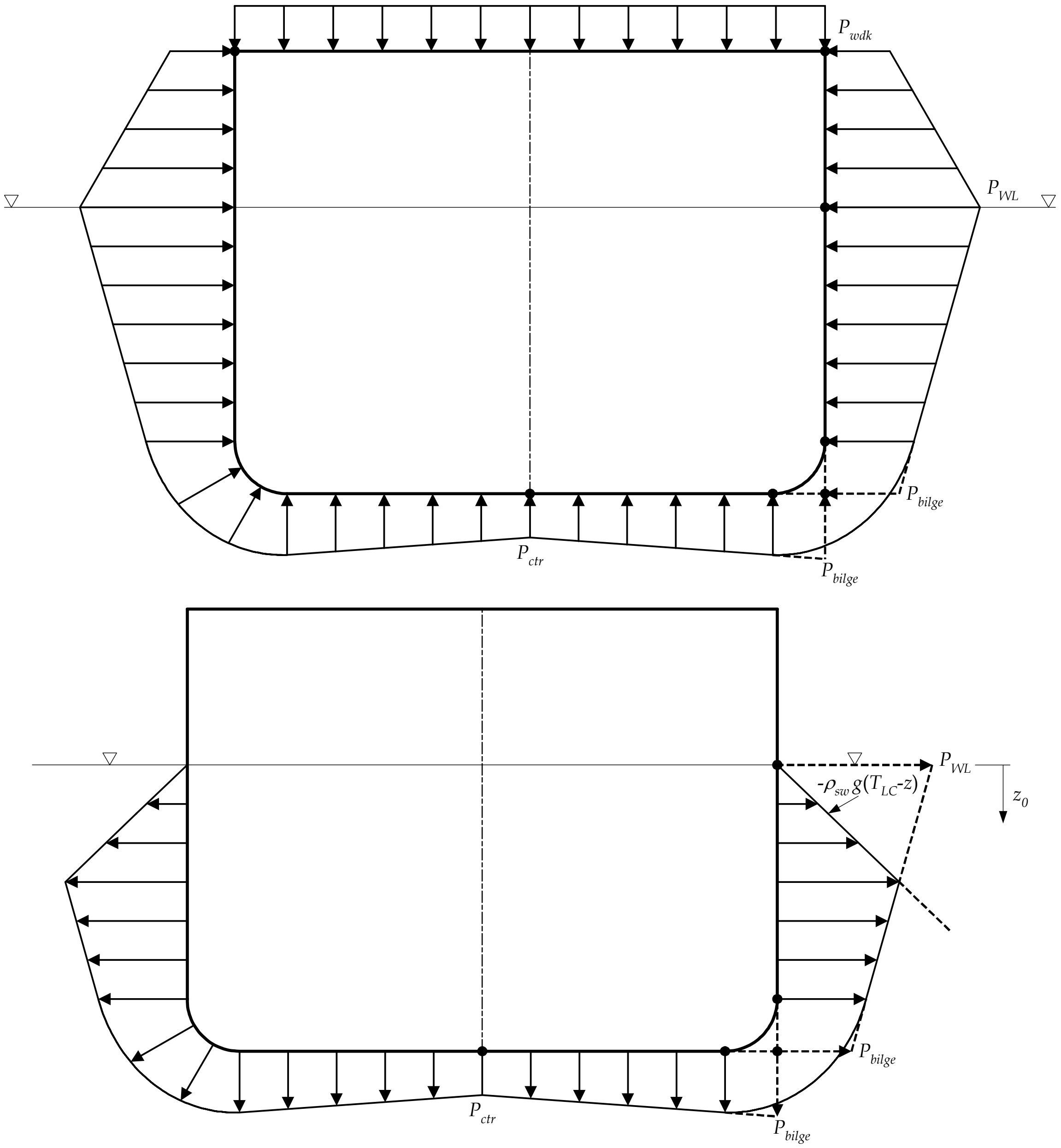
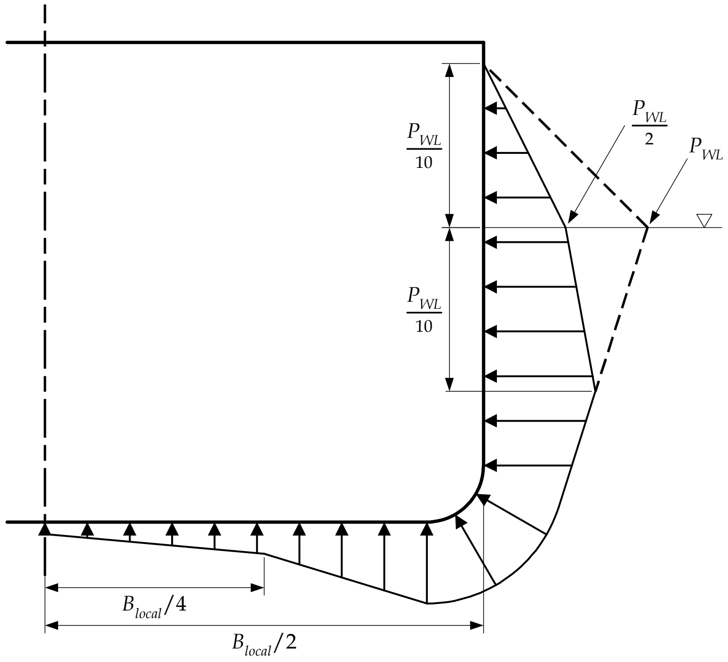


Figure 7.3.b
Girth wise Distribution of Dynamic Wave Pressure for Fatigue Strength Assessment



3.5.2.d The general expression of P_1-wave pressure is a combination of approximately 80% of the greatest wave induced pressures resulting from pitch/heave-motion and approximately 40% of the wave induced pressure from roll motion.

Where:

$3f_sC_{wv}$	represents the induced pressure from pitch and heave motion
$0.8C_{wv}$	represents a stow-up effect of incoming wave
$\frac{135B_{local}}{(B+75)}$	expresses contribution from the roll motion at the ship-side
$1.2(T_{LC}-z)$	accounts for the dynamic wave reduction of pressure down along ship hull
$f_{nl\text{-}P1}$	non-linear correction factor
f_{prob}	probability adjustment factor
f_l	factor which reduces the pressure on the bottom towards the centre-line, generally a reduction of the roll-effect, see *Table 7.3.3* and *Table 7.3.4*
z	vertical coordinate according to global coordinate system, measured from the base-line

3.5.2.e The formulation for P_2 is dominated by the pressures due to roll and heave motion, which are greater in beam sea wave conditions than in head seas wave conditions. P_2 is constant along the ship-length for a given transverse distance from the centreline, and vertical distance from base line.

Where:

$\frac{\theta}{2}B_{local}$	takes into account the effect of roll motion.
$f_T C_b \frac{B_{local}+0.8C_{wv}}{14}\left(0.7+\frac{2z}{T_{LC}}\right)$	represents dynamic pressures due to the incoming wave, like excitation and build-up of wave. The reduction down along the side is taken care of in this term. This term is corrected with f_T, which represents the difference depending on the draught of the loading condition.

3.5.2.f The P_1-pressure has a non-linear correction factor, $f_{nl\text{-}P1}$, of 0.9, while a correction, $f_{nl\text{-}P2}$, of 0.65 is used for the P_2. $f_{nl\text{-}P2}$ consists of a non-linear correction together with operational considerations. The non-linear correction is assumed to be 0.8125, while a factor of 0.8 is applied for operational consideration. $f_{nl\text{-}P2}$ and $f_{nl\text{-}P2}$ are based on model-tests performed by Class NK.

3.5.2.g f_1 and f_2 are included in both expressions to give a realistic distribution girth wise, see *Figure 7.3.a* and *Figure 7.3.b*.

3.5.2.h Stretching above waterline for scantling requirements and strength assessment is assumed to be 1:1.

3.5.2.i For negative pressures, as is the case in wave troughs, the total pressure can not be less than zero.

3.5.2.j The probability adjustment factor, f_{prob}, for fatigue is taken as 0.5 which gives the best fit with direct calculations. The stretching above waterline for fatigue strength is found by linear interpolation from where the dynamic pressure is zero, and the still waterline, taken as minimum the freeboard height, and maximum 1:1 reduction of the dynamic sea pressure at the still waterline.

3.5.3 Green sea load

3.5.3.a The green sea pressure is taken as a function of the side-shell wave pressure at the deck corner. $P_{1\text{-}dk}$ and $P_{1\text{-}dk}$ results from the P_1 and P_2 respectively.

3.5.3.b The factor $f_{1\text{-}dk}$ represents the dynamic effects due to bow acceleration and plummeting of the green water on board in head sea condition, and applies to the $P_{1\text{-}dk}$ green sea pressure on the fore deck. $f_{1\text{-}dk}$ is constant girthwise, since the green sea load is assumed to come onto deck from the bow, and flow backwards onto the deck.

3.5.3.c For the aft region, an operational factor, f_{op}, is applicable for $P_{1\text{-}dk}$. f_{op} assumes that the ship will not operate in following seas in a severe storm. Hence, the likelihood of encountering waves spilling onto the aft deck is reduced. Consequently a 1 year return period is assumed for the green sea loading on aft deck. f_{op} increases linearly to 1.0 giving full green sea loading at 0.2L forward of aft perpendicular.

3.5.3.d The variation of the f_{2-dk} across the deck represents the green sea load distribution in beam seas. When calculating instantaneous green sea load distribution in beam seas, f_{2-dk} is set to 1 at the deck corner on weather side and to zero at deck corner on lee side, assuming that the side-shell pressure on the lee side will always become zero. The pressure is linearly interpolated between weather and lee side. The factor is a function of the local breadth at the deck, as the weather deck breadth in the forward and aft regions, will be different than the breadth at the still waterline.

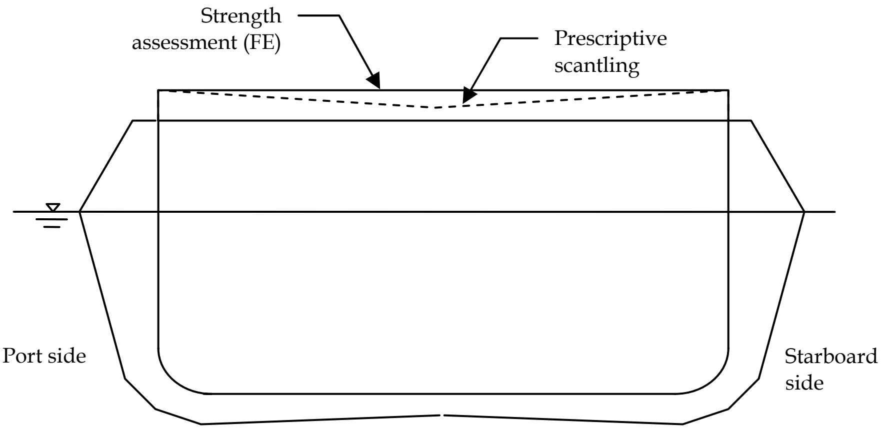
3.5.3.e The green sea load resulting from P_2 pressure at the deck corner is multiplied with 0.8 to represent that the pressures stretching above waterline is less than 1:1, when the wave comes in from the side.

3.5.3.f For strength assessment (FE), the green sea load distribution is obtained by linear interpolation between the green sea pressure on starboard and port side.

3.5.3.g For scantling requirements, the green sea load distribution is applied directly from the formulation. If the pressure on the side-shell does not stretch above the deck corner of the side of the ship which is under consideration, the green sea is taken as zero.

3.5.3.h The procedure for strength assessment (FE) and prescriptive scantling requirements are slightly different. This is justified since the prescriptive rules are evaluating the local structure, and hence the load at other places will not influence the results. Similarly, the green sea pressure distribution during prescriptive evaluation of primary support members is approximated at the middle of the span, see also cases shown in *Figure 7.3.c* to *Figure 7.3.e*.

Figure 7.3.c
Green Sea Load On Weather Deck For A Head Sea Dynamic Load Case



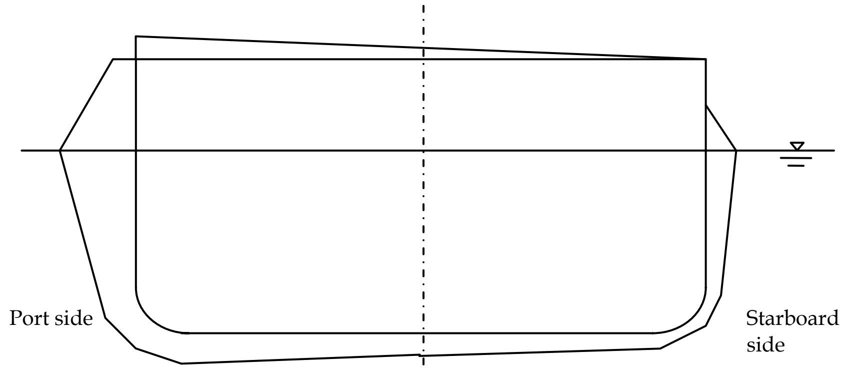
For strength assessment (FE) the green sea load is taken as a uniform distribution across the deck (represented by full-line).

For scantling requirements, the green sea load distribution follows the f_{2-wdk} factor (represented by dashed line).

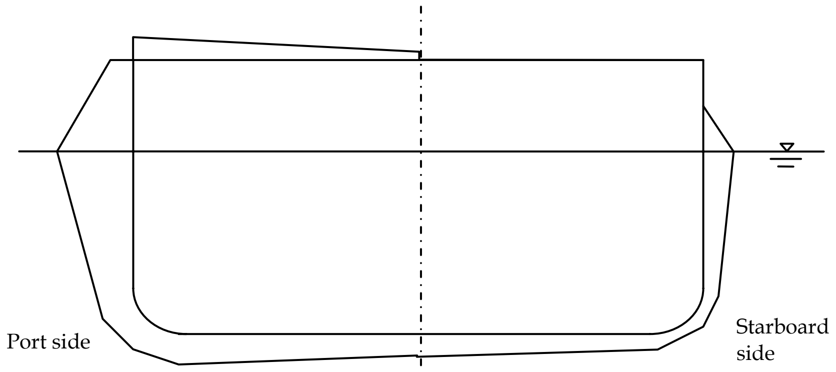
The green sea load is less for the prescriptive scantling requirements than for strength assessment. However the green sea load in the dynamic load case in head sea is not found critical for the deck structure, and the distribution is therefore not important.

Figure 7.3.d
Green Sea Load On Weather Deck For A Beam Sea Dynamic Load Case

Strength assessment (FE)



Prescriptive scantling requirements

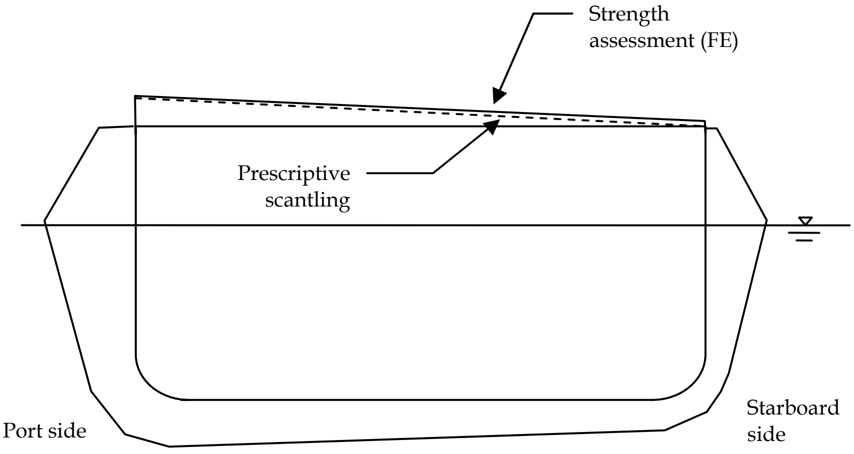


The first figure represents strength assessment (FE) and the second figure gives the distribution for scantling requirements.

When assessing the port-side, the pressure distribution is the same. For scantling requirements, no load is applied to the starboard side.

Since the green sea on port side is larger than the starboard side, the port side pressure will be critical for scantling requirements.

Figure 7.3.e
Green Sea Load On Weather Deck For A Beam/Oblique Sea Dynamic Load Case



For strength assessment (FE) the green sea load distribution is taken as a the full-line.

For scantling requirements, the green sea load distribution follows the dashed line.

The deviation between the two distributions is in such small in the region of interest (hence, where the green sea is greatest). This is considered an artificial case, as the wave pressure will practically never stretch above weather-deck on both sides.

3.5.3.i For fatigue strength, the green sea loads is taken as zero as the effect of green sea loading on the fatigue damage is negligible.

3.5.4 Dynamic tank pressure

3.5.4.a The rule formulations for dynamic tank pressure due to ship motion are developed under the assumption that a tank is completely filled with liquid and the tank wall is rigid. Since the cargo tanks will normally not be more than 98% full, the tank pressure for cargo tanks include an ullage factor. It is further assumed that it is sufficient to derive the tank pressure from the ships acceleration at the centre of gravity of the tank. The sloshing loads due to a partially filled tank is treated separately, see *4.2*.

3.5.4.b The pressure is assumed to be the linear summation of the basic pressure components due to the three acceleration components, which also include pitch and roll motion. For strength assessment by prescriptive rule requirements and FE analysis the pressure components are combined based on dynamic load combination factors found from Equivalent Design Waves, *see 6.3.7*, giving the simultaneously acting distribution of tank pressure.

3.5.4.c For strength assessment by prescriptive rule requirements and by FE-analysis, the reference points for the tank pressure-head due to vertical, transverse and longitudinal acceleration is evaluated in the following:

(a) For vertical acceleration, the reference point is taken as the top of the tank. There are three scenarios of dynamic tank pressure due to vertical acceleration a_v, in which Case 1 and Case 2 are realistic and shown in *Figure 7.3.f*:

- Case 1: $a_v > 0$

The vertical acceleration is positive, resulting in an increase of tank pressure. The reference point for the tank pressure will be the top of tank, same as it for static tank.

- Case 2: $a_v < 0$ and $> -g$

The vertical acceleration is negative, reducing the tank pressure. The total acceleration is still positive and the reference point is top of tank.

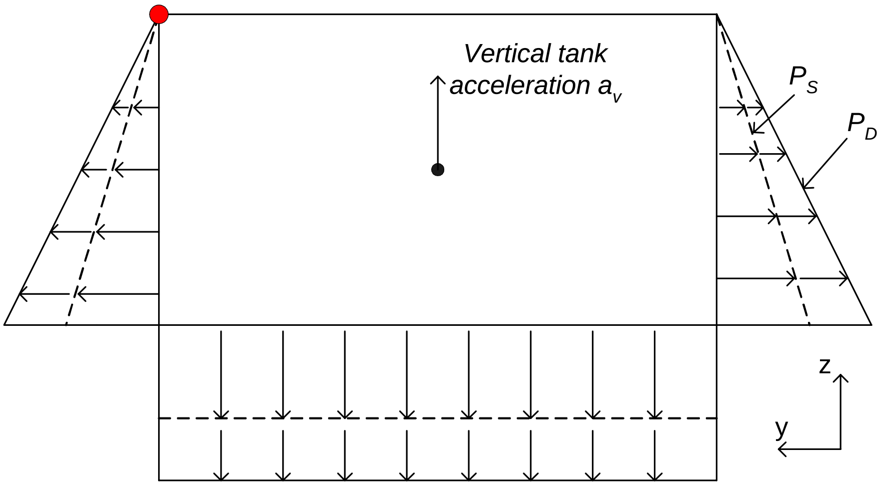
- Case 3: $a_v < - g$

For a tank which is designed for ballast water exchange by flow through, the vertical reference point is taken as the top of air-pipe or top of overflow, whichever is smaller, since the liquid in the pipe will also add to the total tank pressure.

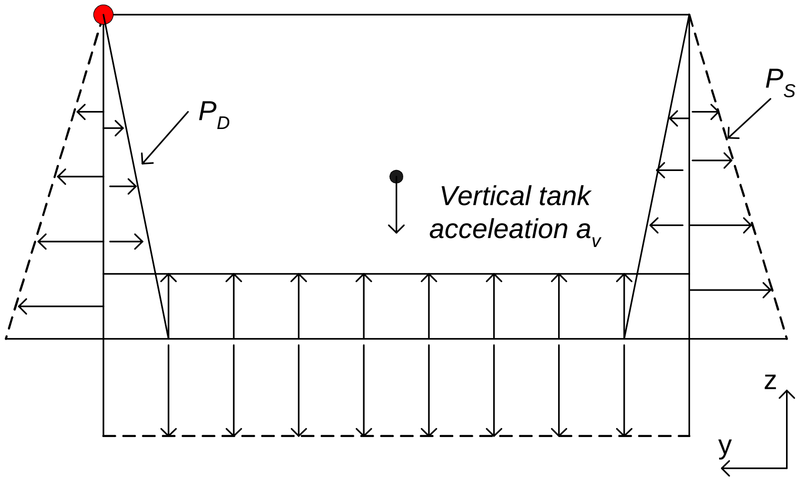
(b) The dynamic pressure due to the transverse acceleration a_t is treated the same way as the static pressure caused by the gravitational acceleration g. For transverse acceleration, the reference point is taken as the top of tank on port side for positive transverse acceleration and as top of tank on starboard side for negative transverse acceleration. The reference point is taken as the corner where the air-pocket will be located, see *Figure 7.3g* which illustrates the case with positive transverse acceleration. The surface of the liquid will be normal to the total acceleration, and the tank pressure increases linearly with the distance normal to the free surface.

Figure 7.3.f
S + D (Static + Dynamic) Tank Pressure Due To Vertical Acceleration

Case 1: $a_v > 0$



Case2: $a_v < 0$

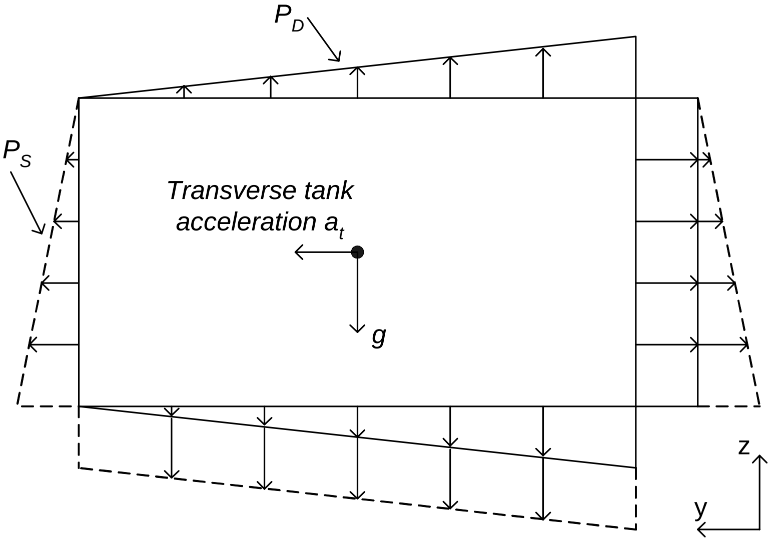


Where:

P_s	is static tank pressure due to gravity $= \rho g(z - z_0)$
P_D	is dynamic pressure due to vertical acceleration a_v $= \rho a_v(z - z_0)$
z-z_0	is the vertical distance from the load point to the reference point

Figure 7.3.g

S+D (Static plus Dynamic) Tank Pressure Due To Transverse Acceleration



Where:

P_s is static tank pressure due to gravity

$= \rho g(z - z_0)$

z-z_0 is the vertical distance from the load point to the reference point

P_D is dynamic pressure due to transverse acceleration a_t

$= \rho a_t(y - y_0)$

y-y_0 is the transverse distance from the load point to the reference point

For a ballast tank, we get the same trend. There are however two different scenarios, see *Figure 7.3.h*. In case 1, the tangent of the free surface, line of zero pressure, locates the reference point at the tank top corner. For case 2, the reference point is located at the bottom tank corner. The reference point will shift from case 1 to case 2 at a critical transverse acceleration, $a_{t\text{-}crit}$, given as:

$$a_t > a_{t-crit} = \frac{b_{tk} - b_{tt}}{h_{tk} - h_{db}} g$$

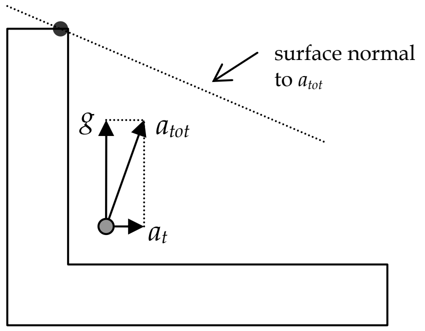
Where:

b_{tk}	tank breadth, in m
b_{tt}	tank breadth at tank top, in m
h_{tk}	tank height, in m
h_{db}	double bottom height, in m

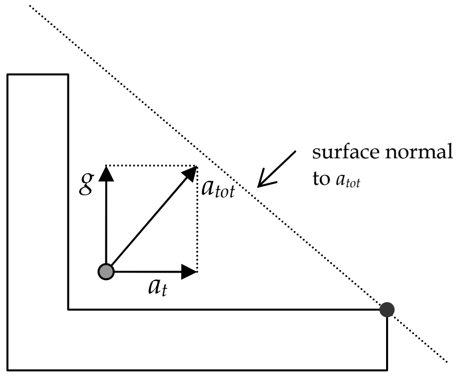
Case 2 is considered unlikely; hence the situation when the reference point is located at the top of the tank is taken as the default in the rules.

Figure 7.3.h
Transverse Reference-Point For A Ballast Tank

Case 1: $a_t < a_{t\text{-}crit}$



Case 2: $a_t > a_{t\text{-}crit}$



Where:

a_t	is transverse tank acceleration
$-g$	is gravitational acceleration as "felt" by tank boundary
a_{tot}	is total acceleration as "felt" by tank boundary

Similarly as for tank pressure due to transverse acceleration, the reference point due to longitudinal acceleration, is taken as the top of tank on aft transverse bulkhead for positive longitudinal acceleration and as top of tank on forward transverse bulkhead for negative longitudinal acceleration.

3.5.4.d The reference point for dynamic tank pressure is derived under the assumption of 100% tank-filling. For cargo tanks, which are not filled beyond 98%, this is a conservative assumption, especially for dynamic tank pressure due to transverse and longitudinal acceleration. A factor to reduce the pressure for cargo tanks is therefore given. This factor represents the difference between the tank pressure at 98% tank filling and 100% tank filling at the tank sides. Hence the ullage-factor is defined as:

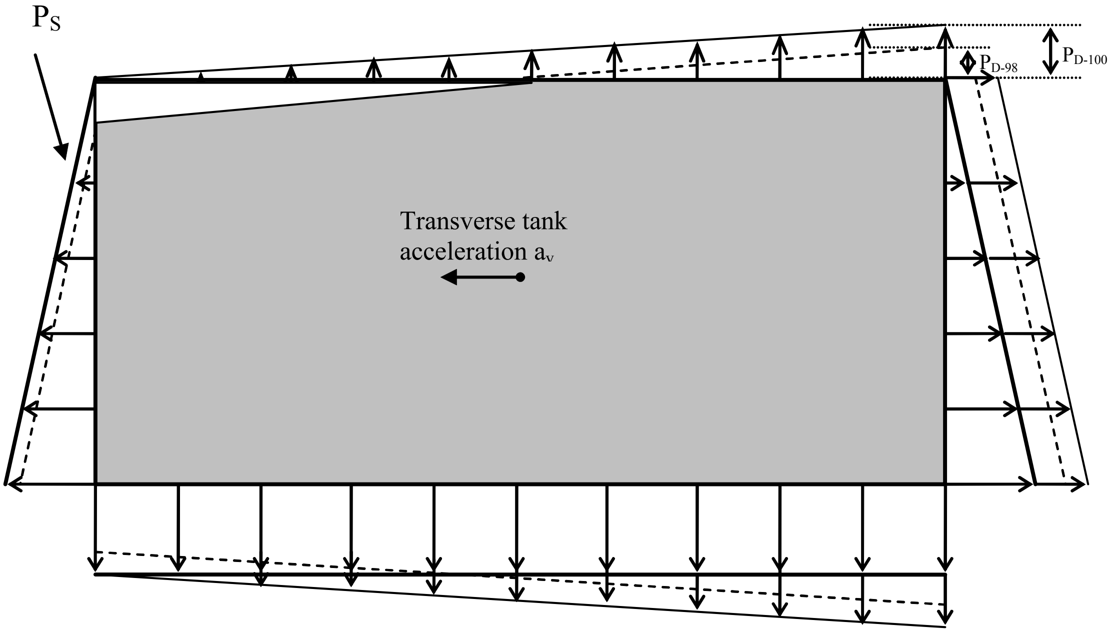
$$f_{ullage} = \frac{P_{D-98}}{P_{D-100}}$$

Where:

P_{98} tank pressure due to transverse acceleration at 98% filling at tank side, in kN/m², see also *Figure 7.3.i*

P_{100} tank pressure due to transverse acceleration at 100% filling at tank side, in kN/m², see also *Figure 7.3.i*

Figure 7.3.i
Tank Pressure Due To Transverse or Longitudinal Acceleration



Where:

P_{98} tank pressure due to transverse acceleration at 98% filling at tank side, in kN/m²

P_{100} tank pressure due to transverse acceleration at 100% filling at tank side, in kN/m²

The dashed line represents the pressure-distribution due to transverse acceleration based on a 98% full tank, the full line shows the pressure-distribution for a 98% filling. The bold line illustrates the static tank pressure.

P_{D-98} and P_{D-100} have been calculated quasi-statically. Keeping in mind that the surface of the liquid will be normal to the total acceleration, and the tank pressure increases linearly with the distance normal to the free surface, P_{D-98} and P_{D-100} have been calculated for a number of test vessels.

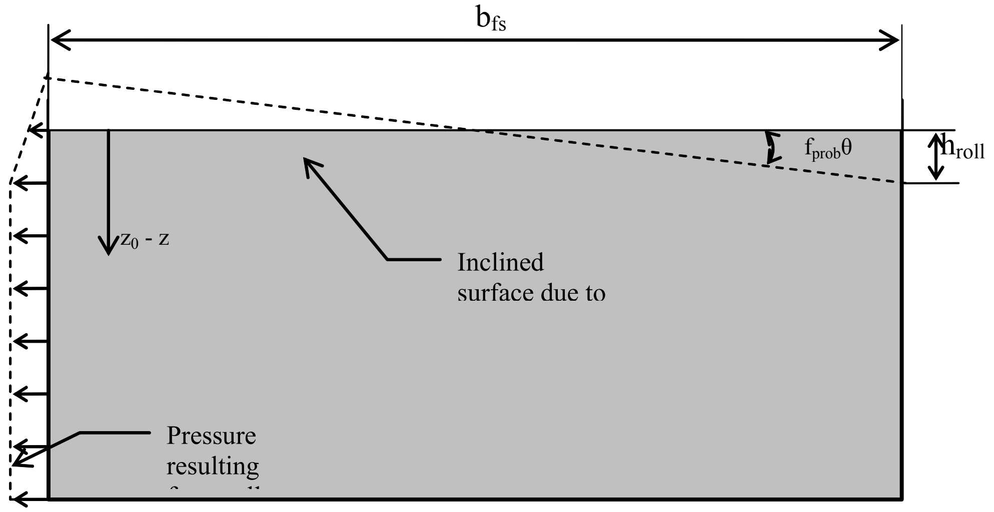
The average ullage factor due to transverse acceleration and longitudinal calculation was calculated to be 0.67 and 0.62, respectively. The calculations are based on the fulload conditions of the ships, using *GM* and $r_{roll\text{-}gyr}$ as 0.12*B* and 0.35*B* respectively, and the heavy ballast condition, using *GM* and $r_{roll\text{-}gyr}$ as 0.33*B* and 0.45*B* respectively. The results show same results for fulload and ballast conditions.

3.5.4.e Unlike the scantling requirements and strength assessment (FE) which require an instantaneous distribution of tank pressure for a dynamic load case, fatigue strength assessment requires the envelope distribution of tank pressure on the tank surface at a 10^{-4} probability level. The tank pressure dynamic amplitude for fatigue strength is defined as a half of the tank pressure dynamic range that is a peak-to-peak value of the tank pressure load. This approximation allows the dynamic internal pressure become cyclic loads for fatigue strength assessment. Furthermore this approximation still gives the exact tank pressure dynamic range on the tank walls.

3.5.4.f For fatigue assessment the combination of pressure components is based on an average load combination factor for the long-term pressure distribution in a tank. They are developed based on direct calculations of the long-term envelope dynamic tank pressure at a 10^{-4} probability level with all wave headings considered. Since the geometry and centre of gravity of cargo tanks and ballast tanks is different, the dynamic combination factors were found to be different.

3.5.4.g The ullage factor for fatigue accounts for the tank being 98% full. Since it is not 100% full, the upper part of the tank will be intermittent wet and dry (similar as side-shell region around waterline). To account for this ullage factors are added for tank pressure resulting from transverse and longitudinal accelerations respectively. *Figure 7.3.j* visualizes the effect.

Figure 7.3.j
Tank Pressure Due To Roll of Tank



At a distance h_{roll} below the free surface the full pressure range is achieved, and h_{roll} above the free surface the pressure range is taken as zero. Between the two points the pressure range varies linearly, so at the free surface the tank pressure range is found to be half of full contribution from transverse acceleration.

3.5.5 Dynamic deck pressure from distributed loading

3.5.5.a The pressure due to uniformly distributed mass on deck is given.

3.5.5.b As only deck, hatch cover and inner bottom loading, (i.e. only horizontal load areas) are considered; the transverse and longitudinal accelerations can be neglected.

3.5.6 Dynamic loads from heavy units

3.5.6.a The force due to loads from heavy units exposed to vertical, transverse and longitudinal acceleration is included.

4 SLOSHING AND IMPACT LOADS

4.1 General

4.1.1 Load Components

4.1.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

4.2 Sloshing Pressure in Tanks

4.2.1 Application and limitations

4.2.1.a The calculated sloshing pressures are based on the total movement of the tank liquid as subjected to ship motions and accelerations.

4.2.1.b The sloshing pressure is applicable for tanks with effective breadth and length within $b_{slh} \leq 0.56B$ and $l_{slh} \leq 0.13L$ respectively.

4.2.1.c As a result of *MARPOL* requirements, it is rare to see an oil tanker that has an effective tank length greater than $0.13L$. Likewise the stability requirements do not allow larger ships to have full breadth cargo tanks. A full breadth forepeak ballast tank will generally have a significant amount of internal stiffeners and webs that reduce the effective sloshing breadth. Based on this no effort was put on unifying the sloshing loads for such tanks in the present version of the common Rules.

4.2.1.d All structural members in tanks containing liquid are subject to sloshing pressure. The minimum sloshing pressure applies to all structural members while the calculated sloshing pressure applies at the tank ends.

4.2.1.e The longitudinal and transverse sloshing pressures are maximum values at a given probability level and are assumed to be independent of each other.

4.2.1.f The Rule minimum standard is based on no filling restrictions in the cargo tank.

4.2.1.g The calculated sloshing pressure is associated with a normal load level. The evaluation of the structure against sloshing loads is covered by Design Load Combination 3 and Acceptance Criteria Set AC1 as shown in *Section 2/Table 2.5.13 of the Rules*.

4.2.2 Sloshing pressure due to longitudinal liquid motion

4.2.2.a The formulation for the sloshing pressures is based on *DNV Rule Pt.3 Ch.1 Sec.4 C306*.

4.2.2.b The sloshing pressure formulation takes into account the internal web-frames and transverse swash-bulkheads that reduce the fluid motion in the tanks, by reducing the effective sloshing length of the tank.

4.2.2.c The sloshing pressure acting on the transverse bulkhead and transverse wash-bulkhead are different since the effective sloshing length is different.

4.2.2.d The maximum calculated sloshing pressure is normally found at a filling level of $0.7h_{max.}$ This will be the case for all tank configurations without wash bulkheads or transverse struts, i.e. with only vertical webs in the tank. For tanks with a strut/cross tie the maximum sloshing pressure will typically be found at a filling level between 0.7h_{max} and 0.8h_{max}.

4.2.2.e The sloshing pressure due to longitudinal fluid motion is also assumed to act on the 1st internal web-frame away from the transverse tight/wash-bulkhead. This pressure arises due to the reflection of the liquid from the transverse bulkhead under consideration and is consequently lower than pressure acting directly on the transverse bulkhead. The closer the web-frame is to the bulkhead in question the higher the pressure will be.

4.2.2.f The distribution of sloshing pressure on web-frames and stringers gives a reduction towards the free edge to account for limited possibility of pressure build up.

4.2.3 Sloshing pressure due to transverse liquid motion

4.2.3.a The formulation for the sloshing pressures is based on *DNV Rule Pt.3 Ch.1 Sec.4 C306*.

4.2.3.b The *GM* value of 0.33*B* is representative for a ballast condition and hence is used as the basis for calculation of sloshing pressures in the ballast tank. The *GM* value of 0.24*B* is representative for a part load condition with some cargo tanks full and some empty or with reduced filling.

4.2.3.c The sloshing pressure formulation takes into account the internal longitudinal girders and longitudinal wash-bulkheads that reduce the fluid motion in the tanks. As noted in the Rule the sloshing breadth in cargo tanks will normally be equal to the tank breadth. The reduced sloshing breadth will mainly be applicable for sloshing assessment of aft- and fore peak ballast tanks.

4.2.3.d The sloshing pressure acting on the tank-sides/longitudinal bulkheads and longitudinal wash-bulkhead are different due to different sloshing breadths. This gives lower sloshing pressure in way of wash bulkheads compared to tight bulkheads.

4.2.3.e The sloshing pressure due to transverse fluid motion is also assumed to act on the 1st internal girder away from the longitudinal tight/wash bulkhead. The pressure is however reduced somewhat from that calculated for the longitudinal bulkhead, as the sloshing pressure on the frame arises as a reflection of the liquid motion acting on the longitudinal bulkhead. The greater distance the girder is away from the bulkhead in question the lower the pressure is.

4.2.3.f The distribution of sloshing pressure on girders and stringers gives a reduction towards the free edge to account for limited possibility of pressure build up.

4.2.4 Minimum sloshing pressure

4.2.4.a The minimum sloshing pressure, $P_{slh\text{-}min}$, is included in order to ensure that all internal structures are able to withstand the pressures due to fluid motion in the tank.

4.3 Bottom Slamming Loads

4.3.1 Application and limitations

4.3.1.a The Rules cover standard tanker designs with length greater than or equal to 150 metres hence the section only caters for designs with a lower limit of C_b of 0.7.

4.3.1.b The bottom slamming requirement applies for ships which have a forward bottom slamming draught at F.P. between 0.02*L* and 0.045*L*. The limits are inline with the worst existing limits of ABS, LR and DNV rules.

4.3.2 Slamming pressure

4.3.2.a The bottom slamming pressure formula based on *LR Rules Pt 3, Ch 5,1.5.8*. During development it was confirmed that the strength requirements for bottom slamming of ABS, DNV and LR utilise load models with similar load magnitude.

4.3.2.b The reduction of the bottom slamming pressure to account for the counter-acting head of ballast water is allowed and is based on *LR Rules Pt 3, Ch 5,1.5.8*.

4.3.2.c The LR Rules slamming pressure formula is an empirical formulation based on the results of a study into the bottom slamming pressures for a range of general cargo and full form ships using the Ochi-Motter approach. In this study, the slamming velocities and relative vertical motions were derived using ship motion analysis and based on short term statistical analysis of motions in North Atlantic seastates. Bow shapes of typical ships were used to derive the impact shape coefficients. The study included forward speed.

4.3.2.d The LR rule application has been revised with respect to the forward draughts to be used for the bottom slamming assessment in order to match the Rule design basis. Hence two sets of minimum draughts forward are to be specified, see *Section 8/1.1.1 of the Rules*:

- one set specifies the minimum draught forward with each double bottom ballast tank (or fore peak/forward deep tank) empty
- the other set specifies the minimum draught forward applicable with each ballast tank is filled, hence reducing the effective slamming pressure due to the counter-acting ballast water .

4.4 Bow Impact loads

4.4.1 Application and limitations

4.4.1.a The Rules cover standard tanker design with length greater than or equal to 150 metres.

4.4.2 Bow impact pressure

4.4.2.a The bow impact pressure formula is based on *ABS Rules 5.1.3/13*, whereas during development it was confirmed that the strength requirements for bow impact of ABS, DNV and LR utilise load models with similar load magnitude.

4.4.2.b The bow impact pressure is due to the frontal impact force in longitudinal direction, which is converted to the pressure to the bow area.

4.4.2.c The bow impact pressure is approximately proportional to the square of relative impact velocity based on experimental and theoretical studies by Hagiwara and Yuhara:

$$P_{im} \propto \rho V_{im}^2$$

Where:

ρ density of sea-water, in kg/m^3

V_{im} relative impact velocity, in m/s^2

4.4.2.d The impact velocity, V_{im} represents the relative velocity between the ships forward speed and the relative velocity of the fluid due to wave. The ship speed is estimated to be 75% of the ship service speed, taking into account voluntary and involuntary speed reduction due to slamming, bow sub-mergence and added wave resistance. The velocity of the critical encountering waves is assumed to a wave length of 65% of the ship-length. These two components are estimated based on the study by Ochi and Tasai.

4.4.2.e The formulation does not include any contribution from bow flare slamming pressure.

5 ACCIDENTAL LOADS

5.1 Flooded Condition

5.1.1 Tank Pressure

5.1.1.a The tank pressure in accidental flooding/damage condition is taken as $P_{in\text{-}flood}$, see *2.2.3*.

6 COMBINATION OF LOADS

6.1 General

6.1.1 Application

6.1.1.a The following Design Load Combinations are defined in the Rules, see *Table 2.5.1 of the Rules*:

(a) Static Design Load Combination (S)
(b) Static plus Dynamic Design Load Combination (S + D)
(c) Impact and slamming Design Load Combination (Impact)
(d) Sloshing Design Load Combination (Sloshing)
(e) Cyclic loads (Fatigue)
(f) Accidental Design Load Combination (A)

6.1.1.b *Table 7.6.a* shows the load components to be considered in each Design Load Combination. In *Table 7.6.1 of the Rules* it is only *S*, *S + D* and *A* that are given. The remaining design loads are covered in their respective rule requirements.

6.2 Design Load Combination

6.2.1 General

6.2.1.a *Table 7.6.a* gives the load components to be considered during the structural evaluation for all the defined design load combinations.

6.2.2 Static design load combination (S)

6.2.2.a The hull girder loads cover the greatest harbour permissible vertical bending moments and shear forces together are assumed to occur together with the greatest static local tank and sea pressures including structural testing.

6.2.3 Static plus Dynamic design load combination (S + D)

6.2.3.a The static plus dynamic loads give the most onerous combination of static loads and a realistic combination of simultaneously acting dynamic loads at a 10^{-8} probability level.

6.2.3.b The static hull girder loads are taken as the permissible still water hull girder limits for sea-going given in *Section 7/2.1 of the Rules*. No reduction of the permissible hull girder bending moment is given due to joint probability of occurrence of the permissible still water bending and heavy weather.

6.2.3.c The static sea pressure is based on the structurally most onerous draught for each structural detail. The static tank pressures are taken as the greatest pressure during voyage for a tank including the added pressure head and possible overpressure for tanks which are designed for ballast water exchange by flow through.

6.2.3.d For tanks designed for sequentially filling, it is assumed that the time duration of possible overfilling is short and hence the added pressure head and over pressure may be ignored.

Table 7.6.a
Load Scenarios and Load Combination

Load Scenario			Harbour Loads	Operational Loads	Impact loads	Sloshing Loads	Accidental flooding loads	Cyclic loads
Design Load Combination			**S**	**S + D**	**Impact**	**Sloshing**	**A**	**Fatigue**
Hull Girder	$M_{v\text{-}total}$		$M_{sw\text{-}perm\text{-}harb}$	$M_{sw\text{-}perm\text{-}sea} + M_{wv}$	-	$M_{sw\text{-}perm\text{-}harb}$	-	M_{wv}
	$M_{h\text{-}total}$		-	M_h	-	-	-	$M_{wv\text{-}h}$
	Q		$Q_{sw\text{-}perm\text{-}harb}$	$Q_{sw\text{-}perm\text{-}sea} + Q_{wv}$	-	-	-	-
Local Loads	P_{ex}	**Weather Deck**	-	P_{wdk}	-	-	-	-
		Hull envelope	P_{hys}	$P_{hys} + P_{ex\text{-}dyn}$	P_{im} and P_{slm}	-	-	$P_{ex\text{-}amp}$
	P_{in}	**Ballast tanks (BWE with sequential filling method)**	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air} + P_{drop}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	-	P_{slh}	$P_{in\text{-}flood}$	$P_{in\text{-}amp}$
		Ballast tanks (BWE with flow-through method)	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air} + P_{drop}$	$P_{in\text{-}air} + P_{drop} + P_{in\text{-}dyn}$	-	P_{slh}	$P_{in\text{-}flood}$	$P_{in\text{-}amp}$
		Cargo tanks including cargo tanks designed for filling with water ballast	$P_{in\text{-}test}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	-	P_{slh}	-	$P_{in\text{-}amp}$
		Other tanks with liquid filling	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	-	P_{slh}	$P_{in\text{-}flood}$	-
		Watertight boundaries	-	-	-	-	$P_{in\text{-}flood}$	-
	P_{dk}	**Internal decks for dry spaces**	P_{stat}	$P_{stat} + P_{dyn}$	-	-	-	-
		Decks for heavy units	F_{stat}	$F_{stat} + F_v + F_t + F_{lng}$	-	-	-	-

Table 7.6.a (Continued)
Load Scenarios and Load Combination

Where:		
M	design vertical bending moment, in kNm	
$M_{sw-perm-harb}$	harbour permissible still water vertical bending moment, in kNm	see *2.1.1*
$M_{sw-perm-sea}$	seagoing permissible still water vertical bending moment, in kNm	see *2.1.1*
M_{wv}	vertical wave bending moment for a considered dynamic load case, in kNm	see *6.2.2*
$M_{h-total}$	design horizontal bending moment, in kNm	
M_h	horizontal wave bending moment for a considered dynamic load case, in kNm	see *6.2.3*
Q	design vertical shear force, in kN	
$Q_{sw-perm-harb}$	harbour permissible still water vertical shear force, in kNm	see *2.1.1*
$Q_{sw-perm-sea}$	seagoing permissible still water vertical shear force, in kNm	see *2.1.1*
Q_{wv}	vertical wave shear force for a considered dynamic load case	see *6.2.4*
P_{ex}	design sea pressure	
P_{hys}	static sea pressure at considered draught	see *2.2.2*
P_{ex-dyn}	dynamic wave pressure for a considered dynamic load case	see *6.2.5*
P_{stat}	static deck load	see *2.2.4* and *2.2.5*
P_{dyn}	dynamic deck load	see *3.5.5* and *3.5.6*
P_{slm}	bottom slamming pressure	see *4.3*
P_{im}	bow impact pressure	see *4.4*
P_{in}	design tank pressure	
$P_{in-test}$	tank testing pressure	see *2.2.3*
P_{in-air}	static tank pressure measured from top of air pipe	see *2.2.3*
P_{drop}	Air pipe overfilling tank pressure	see *2.2.3*
P_{in-tk}	tank pressure measured from top of tank to load point	see *2.2.3*
P_{in-dyn}	dynamic tank pressure for a considered dynamic load case	see *6.2.6*
$P_{in-flood}$	pressure in flooded/damaged condition	see *2.2.3*
P_{slh}	sloshing pressure, taken as the greatest of $P_{slh-lng}$, P_{slh-t}, $P_{slh-ref}$, $P_{slh-grd}$ and $P_{slh-min}$	see *4.2*

6.2.4 Sloshing design load combination

6.2.4.a For evaluation of structure for sloshing loads, the pressures given in *Section 7/4.2 of the Rules* are considered during strength evaluation. The harbour still water bending moments is considered for the permissible stress. This combination is not explicitly given in *Table 7.6.1 of the Rules*, but is given in *Section 8/6.2 of the Rules.*

6.2.5 Impact and slamming design load combination

6.2.5.a For bottom slamming and bow impact loads, the pressures given in *Section 7/4.3* and *Section 7/4.4 of the Rules* are considered during strength evaluation. Hull girder loads are considered negligible in the region under consideration. The design loads are not explicitly given in *Table 7.6.1 of the Rules*, but is given in *Section 8/6.3* and *Section 8/6.4 of the Rules*.

6.2.6 Accidental flooding design load combination

6.2.6.a The hull girder loads are not explicitly addressed by the Rules, or the statutory requirements, since the loads due to flooding for a oil tanker are not that different to the normal operational loads. Hence, the condition is considered to be covered by the other design load combinations.

6.2.7 Fatigue design loads

6.2.7.a For fatigue the hull girder bending loads and local loads from sea and tank pressure at a 10^{-4} probability level are considered. The fatigue loads are explicitly given in *Section 7/3 of the Rules* and are referred to directly. The combined effect on the fatigue life is considered on the stress level, see *Appendix C/1.4.4.e*.

6.3 Application of Dynamic Loads

6.3.1 Heading correction factor and dynamic load combination factors

6.3.1.a The dynamic loads are given for several dynamic load cases, which contain dynamic load combination factors (LCF) for each load component. The LCF's are multiplied with their respective load envelope value at 10^{-8} probability level to obtain the simultaneously acting load components for a particular design dynamic load combination case. Each dynamic load case is based on maximising one critical load component. The load is maximised by placing the ship in a wave which reproduces the envelope value at 10^{-8} probability level. A "snap-shot" of the other dynamic loads acting simultaneously as the maximised response, is taken. The ratios between the values of these dynamic loads at the "snap-shot" and their respective longterm envelope values give the dynamic load combination factors for each dynamic load case. Hence:

$$LCF = \frac{"snapshot\ value"}{Longterm\ value}$$

This method of finding dynamic load combination factors is called Equivalent Design Wave concept (EDW).

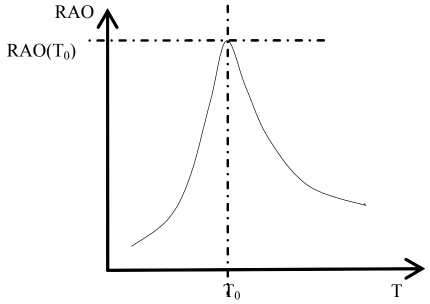
6.3.1.b An equivalent design wave is defined as the regular wave which gives the same response value as the reference design value, hence the envelope value at a 10^{-8} probability level of the maximized response. The EDW is defined based on a given wave period, T_0, the envelope longterm value and the transfer-function of the maximised response. The wave amplitude is given by:

$$A_{EDW}(T_0)=\frac{Longterm\ value}{RAO(T_0)}$$

Where:

A_{EDW}	EDW amplitude, in m
T_0	EDW period, see *Figure 7.6.a*, in sec
RAO	Response amplitude Operator, here taken at period T_0

Figure 7.6.a
Illustration of a RAO



6.3.1.c Mathematically the dynamic load combination factor for a load component *j*, when maximizing load component *i*, is given by:

$$LCF_j=\frac{\text{"snapshot value"}_j}{\text{Longterm value}_j}=\frac{A_{EDW-i}(T_i)\times RAO_j(T_i)\times\cos(\Delta\varepsilon)}{\text{Longterm value}_j}$$

Where:

A_{EDW-i}	amplitude of the equivalent design wave for maximised response *i*, in m
RAO_j	Response Amplitude Operator of response *j*
$\Delta\varepsilon$	phase difference between response *i* and response *j* for period T_i, in rad
T_i	EDW period for design wave for response *i*, in sec

At the same time we know that the design wave amplitude for the load component *j* is given by:

$$A_{EDW-j}(T_j)=\frac{\text{Longtermvalue}_j}{RAO_j(T_j)}\ \rightarrow\ \text{Longtermvalue}_j=A_{EDW-j}(T_j)\times RAO_j(T_j)$$

Where:

A_{EDW-j}	amplitude of the equivalent design wave for the response *j*, in m

T_j EDW period for response j, in sec

RAO_j Response amplitude Operator of response j

Hence, the load combination factor is given by:

$$LCF = \frac{A_{EDW-i}(T_i)}{A_{EDW-j}(T_j)} \times \frac{RAO_j(T_i)}{RAO_j(T_j)} \times \cos(\Delta\varepsilon)$$

6.3.1.d The reference wave period T_0 is normally taken as the period of the peak of the RAO, see *Figure 7.6.a*. However the RAO peak may not coincide with the wave period which contains most wave-energy in the governing wave spectra, see *Figure 7.6.c in 6.5.2.d*. For such cases the period, which statistically gives the greatest contribution to the envelope load, has been chosen as the reference wave period. This has been evaluated to ensure that loads are evaluated at a wave period which contributes most to the envelope load. The RAO curves in such cases have a blunt peak, two peaks, or a very long or short peak–period. The steepness of the EDW at the period T_0 is also considered to avoid unrealistic waves, and hence unrealistic LCFs.

6.3.1.e Generally the loads are maximized in the wave heading which is most severe for the evaluated response. Sometimes it may however be more critical to maximise a load in a wave heading where the load will not become maximum, since the combination of this load together with other load components is considered critical. In such cases the EDW amplitude is adjusted, considering the long term values of the different wave headings. (E.g. vertical acceleration is maximised in head sea, where large hull girder vertical wave bending moments occur, however the greatest vertical acceleration in the midship region occurs for beam sea. The EDW-amplitude has been adjusted to reproduce the greatest long term value in head sea.)

6.3.1.f For dynamic load cases where the load is maximised in beam sea, an operational correction factor, f_β, see *Section 2/7.5.1.3 of the Rules*, of 0.8 is applied to the dynamic load components. The factor of 0.8 reduces the EDW-amplitude to correspond to the wave with a 1 year return period instead of a 25 year return period. The probability of occurrence of this wave is approximately $10^{-6.5}$, which corresponds to a 20% reduction of the load values (~6.5/8). Reducing the return period from 25 years to 1 year takes into account the joint probability of loss of propulsion and similar events that would mean that the ship is unable to maintain steerage in severe weather.

6.3.2 Vertical wave bending moment for a considered dynamic load case

6.3.2.a The simultaneously acting vertical wave bending moment is given. The sign of the dynamic combination factor indicates if the sagging or hogging wave bending moment envelope should be used. When f_{mv} is positive, the hogging moment is used, and when f_{mv} is negative, the sagging moment is used.

6.3.3 Horizontal wave bending moment for a considered dynamic load case

6.3.3.a The simultaneously acting horizontal wave bending moment is given. The sign of the dynamic combination factors indicates if the bending gives tension on the starboard or port side.

6.3.4 Vertical wave shear force for a considered dynamic load case

6.3.4.a The simultaneously acting vertical wave shear force is given. The sign of the dynamic combination factor indicates if the negative or positive wave shear force envelope should be used. When f_{qv} is positive, the positive shear force is used, and when f_{qv} is negative, the negative shear force is used.

6.3.5 Dynamic wave pressure distribution for a considered dynamic load case

6.3.5.a The simultaneously acting wave pressure is given. The girthwise wave pressure distribution is defined by linear interpolation between 5 specified points; at centre-line, at the bilge on port and starboard side and at still waterline of port and starboard side. In the "snap-shot" situation the wave-pressure distributions are considered to be linear between these points. The beam sea factor (*see 6.3.1.f*) is not included for the wave pressure, since it is already implicitly covered by the non-linear factor on the P_2-pressure, see *3.5.2.f.*

6.3.6 Green sea load for a considered dynamic load case

6.3.6.a The simultaneously acting green sea load is given for strength assessment by prescriptive rule requirements and FE-analysis, see *3.5.3*. The green sea is based on the wave pressure at the static waterline, and the simultaneously acting load is adjusted by the LCF of the wave pressure at static waterline.

6.3.7 Dynamic tank pressure for a considered dynamic load case

6.3.7.a The dynamic tank pressure is taken as the linear combination of the dynamic tank pressure distributions from vertical, transverse and longitudinal acceleration.

6.3.7.b The load combination factors for tank pressure are given for each tank. For longitudinal and vertical acceleration, the tank position (port, starboard, centre cargo or double bottom tank) indicates which LCF to use.

6.3.7.c The tank pressure is considered in a quasi-static manner, hence the dynamic tank pressure represents the difference between the pressure distribution of the total tank pressure (resulting from the combined acceleration $g + a$) and the static tank pressure (resulting from g). The reference points are based on the tank being a 100% full, see also *3.5.4.c* for further details.

6.3.7.d For vertical acceleration, the reference point is taken as the highest point in tank, see *3.5.4.c (a)*.

6.3.7.e For transverse acceleration, the reference point is taken as the top of tank on port side for positive transverse acceleration and as top of tank on starboard side for negative transverse acceleration. The reference point is taken as the corner where the air-pocket will be located, see *3.5.4.c (b)*.

6.3.7.f For longitudinal acceleration the reference point is taken as the top of tank on aft transverse bulkhead for positive longitudinal acceleration and as top of tank on forward transverse bulkhead for negative longitudinal acceleration, see *3.5.4.c (c)*.

6.3.7.g For the tanks which are located outside of the cargo region, the dynamic tank pressure is taken as the maximum pressure in the tank at any point, for simplicity.

6.3.8 Dynamic deck loads for a considered dynamic load case

6.3.8.a The simultaneous acting deck loads are given. The LCF's are taken at the centre of gravity of the unit for simplicity.

6.4 Dynamic Load Cases and Dynamic Load Combination Factors for Strength Assessment

6.4.1 General

6.4.1.a The EDW concept is used to develop the dynamic load combination factors for strength assessment by FEM.

6.4.2 FE Dynamic load cases

6.4.2.a *Table 7.6.2 in the Rules*, give the dynamic load cases applicable for strength assessment by FEM.

6.4.2.b The dynamic load cases for FEM are given to reflect the most severe hull girder bending moments and net pressures which the ship will experience amidships. The selected dynamic load cases are those that are considered the most onerous for one or several structural locations, e.g. double bottom and side-shell girders (etc). In addition the most severe shear force is applied in a dynamic load case to ensure that the shear strength of the transverse bulkheads is sufficient.

6.4.2.c Generally the hull girder loads are evaluated amidships while the vertical shear force evaluated at +/- $0.5l_{tk}$ (length of tank) from amidships, whichever gives the greatest shear force. The wave pressure is evaluated amidships and is assumed to be constant over the three hold model. The wave pressure consists of points at waterline, bilge and centreline, and the distribution is given as linear interpolation between those points. The accelerations which define the dynamic tank pressure are evaluated amidships at centre and sides.

6.4.2.d For the dynamic load case for evaluation of shear force, the responses are considered at the quarter length instead of amidships.

6.4.2.e The dynamic load cases used for basis for the dynamic load combination for finite element strength assessment (FE) are the same as used for the prescriptive rule scantling requirements in order to maintain the consistency between the procedures. The whole set consists of 10 dynamic load cases for full load condition and 10 dynamic load cases for ballast condition. The dynamic load cases considered for the determination of scantling requirements in the amidships cargo region are given in *Tables 7.6.g* and *7.6.h.*

6.4.2.f The dynamic load cases used for FE strength assessment are obtained based on applying the following simplifications to consolidate the original full set of dynamic load cases in order to reduce the number of dynamic load cases that need to be analysed:

(a) Combining LCFs for full load and ballast condition as one LCF

(b) Merging of dynamic load cases where LCF values are similar or close in agreement

(c) Eliminate dynamic load cases which do not produce significant loads on the structure, i.e. small net pressure acting on primary support members and small hull girder loads

(d) Only a single LCF is applied to longitudinal acceleration

(e) Adjust LCFs for non-critical hull girder load components to zero for beam sea and oblique sea dynamic load cases. The adjustment is to simplify the application of the procedure and to enable a more logical combination of the beam sea and oblique sea dynamic load cases with loading patterns subjected to either hogging or sagging still water bending moment (negative or positive still water shear force).

The following give details on this procedure for each FEM dynamic load case given in *Table 7.6.2 of the Rules*.

6.4.2.g *FE Dynamic Load Case 1*: Maximum wave sagging bending moment (head sea), see *Table 7.6.b*

- This dynamic load case is obtained by combining the LCF's from *Reference Dynamic Load Case A* (minimising M_{wv}, i.e. sagging bending moment and LCFs given in *Table 7.6.g and Table 7.6.h* is multiplied by a factor -1.0) and *Reference Dynamic Load Case C* (maximising a_v) for the fully loaded condition given in *Table 7.6.g*.
- The LCFs from the two dynamic load cases show close agreement. The combined dynamic load case LCF's are taken as the LCF's resulting from dynamic load case minimising M_{wv} (i.e. sagging bending moment), but with the LCFs for vertical and longitudinal acceleration taken as those from the maximised a_v dynamic load case in head sea achieving greater tank pressure.
- The combined dynamic load case results in a maximum sagging condition and a wave trough amidships combined with large tank pressure, which gives rise to a high net pressure.
- The LCF's from the ballast and full load conditions show very close agreement. However, the full load condition shows a slightly higher vertical acceleration which in turn results in higher tank pressure and net pressure. The full load condition was therefore taken as the reference condition for selecting load combination factors for *FE Dynamic Load Case 1*.
- This dynamic load case is relevant for a static loading pattern with a reduced draught, but with the cargo tank full to obtain maximum net pressure.

6.4.2.h *FE Dynamic Load Case 2*: Maximum hogging wave bending moment (head sea)

- The *FE Dynamic Load Case 2* represents the dynamic load and motion responses which are 180 degrees out of phase with those in *FE Dynamic Load Case 1*. The LCFs for both dynamic load cases are therefore of the same magnitude but have opposite sign.
- The dynamic load case has maximum wave hogging bending moment and a wave crest amidships, which results in a large wave pressure.
- This dynamic load case is relevant in combination with a static loading pattern with an empty tank at maximum draught.

6.4.2.i *FE Dynamic Load Cases 3 and 4*: Maximum positive wave vertical shear force and negative vertical shear force (head sea), see *Table 7.6.c:*

- *FE Dynamic Load Case 3 and 4* are head sea dynamic load cases with LCFs taken directly from the *Reference Dynamic Load Case B* in *Table 7.6.h*. This load case maximises wave vertical shear force at 0.75L forward of A.P.

- The load combination factors for the full load and ballast conditions show close agreement. The dynamic load cases for the FE analysis are based on the greater LCFs of the full load and ballast conditions.
- The pair of dynamic load cases represent load and motion responses of a design wave with a of 180 degrees phase difference. The LCFs for these two load cases are therefore of the same magnitude but have opposite sign.
- The responses are evaluated at the forward quarter length position of the ship at which the wave shear force reaches its maximum value.
- The FE dynamic load cases 3 and 4 occur at 0.75*L* from A.P., and assess the shear capacity of the hull girder longitudinal elements at forward part of the ship.

Table 7.6.b
Derivation of FE Dynamic Load Cases 1 and 2

		Calculated (LCFs)				**FE Analysis (LCFs)**	
Wave direction		**Head (fully loaded)**		**Head (ballast)**		**Head**	
Table reference		*Table 7.6.h*		*Table 7.6.i*		*Table 7.6.2 of the Rules*	
Max response		M_{wv}	a_v	M_{wv}	a_v	M_{wv}	M_{wv}
Reference Dynamic Load Case		**A***	**C**	**A***	**C**		
FE Dynamic Load Case						**1**	**2**
Hull girder	M_{wv}	-1.0	-1.0	-1.0	-1.0	-1.0	+1.0
	Q_{wv}	1.0	0.5	0.9	0.3	1.0	-1.0
	M_{wv-h}	0.0	0.0	0.0	0.0	0.0	0.0
Accelerations for tank pressure calculation	a_{v-mid}	0.2	0.5	0.1	0.4	0.5	-0.5
	$a_{v-ct-pt}$	0.2	0.5	0.1	0.4	0.5	-0.5
	$a_{v-ct-stb}$	0.2	0.5	0.1	0.4	0.5	-0.5
	a_t	0.0	0.0	0.0	0.0	0.0	0.0
	$a_{lng-mid}$	-0.3	-0.6	-0.2	-0.1	-0.6	0.6
	$a_{lng-ct-pt}$	-0.3	-0.6	-0.2	-0.1	-0.6	0.6
	$a_{lng-ct-stb}$	-0.3	-0.6	-0.2	-0.1	-0.6	0.6
	$a_{lng-ctr}$	-0.3	-0.6	-0.2	-0.1	-0.6	0.6
Wave pressure for starboard side	P_{ctr}	-0.7	-0.6	-1.0	-0.8	-0.7	0.7
	P_{bilge}	-0.3	-0.2	-0.3	-0.2	-0.3	0.3
	P_{WL}	-0.3	-0.3	-0.3	-0.2	-0.3	0.3
Wave pressure for port side	P_{ctr}	-0.7	-0.6	-1.0	-0.8	-0.7	0.7
	P_{bilge}	-0.3	-0.2	-0.3	-0.2	-0.3	0.3
	P_{WL}	-0.3	-0.3	-0.3	-0.2	-0.3	0.3

Notes:

1. * factor -1.0 multiplied to LCFs in *Tables 7.6.g and 7.6.h* to obtain minimum (sagging) wave bending moments
2. Sagging bending moment is negative and hogging bending moment is positive

6.4.2.j *FE Dynamic Load Cases 5a and 5b*: Maximum transverse acceleration (beam sea), see *Table 7.6.d:*

- The FE dynamic load cases maximising transverse acceleration are based on the equivalent *Reference Dynamic Load Case I* (maximising negative transverse acceleration) in *Tables 7.6.g* and *7.6.h* in beam sea.
- The LCFs from the full load condition and ballast condition for these load cases show close agreement as shown in *Table 7.6.d*. The LCFs for the FE dynamic load cases are based on the fully load condition but with the LCFs for vertical acceleration and shear force taken as the greatest value from the full load and ballast conditions to obtain slightly conservative loads.
- The LCFs for vertical wave bending moment, horizontal wave bending moment and vertical wave shear force are further adjusted to zero to simplify the application of the procedure.
- The *FE dynamic load cases 5a and 5b* represent the same design wave, but with opposite wave headings, hence maximising transverse acceleration with waves from port side (i.e. weather-side on port side of ship) and starboard side (i.e. weather-side on starboard side of ship) respectively. Both dynamic load cases need to be considered for assessment of non-symmetrical loading pattern and/or structural configuration.

Table 7.6.c Derivation of FE Dynamic Load Cases 3 and 4					
		Calculated (LCFs)		**FE Analysis (LCFs)**	
Wave direction		**Head (fully loaded)**	**Head (ballast)**	**Head**	
Table reference		*Table 7.6.g*	*Table 7.6.h*	*Table 7.6.2 of the Rules*	
Max response		Q_{wv}	Q_{wv}	Q_{wv}	Q_{wv}
Reference Dynamic Load Case		**B**	**B**		
FE Dynamic Load Case				**3**	**4**
Hull girder	M_{wv}	-1.0	-1.0	-1.0	1.0
	Q_{wv}	1.0	1.0	1.0	-1.0
	$M_{wv\text{-}h}$	0.0	0.0	0.0	0.0
Accelerations for tank pressure calculation	$a_{v\text{-}mid}$	0.3	0.2	0.3	-0.3
	$a_{v\text{-}ct\text{-}pt}$	0.3	0.2	0.3	-0.3
	$a_{v\text{-}ct\text{-}stb}$	0.3	0.2	0.3	-0.3
	a_t	0.0	0.0	0.0	0.0
	$a_{lng\text{-}mid}$	-0.6	-0.3	-0.6	0.6
	$a_{lng\text{-}ct\text{-}pt}$	-0.6	-0.3	-0.6	0.6
	$a_{lng\text{-}ct\text{-}stb}$	-0.6	-0.3	-0.6	0.6
	$a_{lng\text{-}ctr}$	-0.6	-0.3	-0.6	0.6
Wave pressure for starboard side	P_{ctr}	0.2	0.3	0.3	-0.3
	P_{bilge}	0.1	0.1	0.1	-0.1
	P_{WL}	0.1	0.1	0.1	-0.1
Wave pressure for port side	P_{ctr}	0.2	0.3	0.3	-0.3
	P_{bilge}	0.1	0.1	0.1	-0.1
	P_{WL}	0.1	0.1	0.1	-0.1
Note: Sagging bending moment is negative and hogging bending moment is positive					

Table 7.6.d
Derivation of FE Dynamic Load Cases 5a and 5b

		Calculated (LCFs)		**FE Analysis (LCFs)**	
Wave direction		**Beam (fully loaded)**	**Beam (ballast)**	**Beam**	
Table reference		*Table 7.6.g*	*Table 7.6.h*	*Table 7.6.2 of the Rules*	
Max response		a_t	a_t	a_t	a_t
Reference Dynamic Load Case		**I**	**I**		
FE Dynamic Load Case				**5a**	**5b**
Hull girder	M_{wv}	-0.1	-0.1	0.0	0.0
	Q_{wv}	0.0	-0.1	0.0	0.0
	M_{wv-h}	0.1	-0.1	0.0	0.0
Accelerations for tank pressure calculation	a_{v-mid}	0.5	0.5	0.5	0.2
	$a_{v-ct-pt}$	0.6	0.8	0.8	0.8
	$a_{v-ct-stb}$	0.2	0.1	0.2	0.5
	a_t	-1.0	-1.0	-1.0	1.0
	$a_{lng-mid}$	-0.1	0.0	-0.1	-0.1
	$a_{lng-ct-pt}$	-0.1	0.0	-0.1	-0.1
	$a_{lng-ct-stb}$	-0.1	0.0	-0.1	-0.1
	$a_{lng-ctr}$	-0.1	0.0	-0.1	-0.1
Wave pressure for starboard side	P_{ctr}	0.5	0.3	0.5	0.5
	P_{bilge}	-0.3	-0.4	-0.3	0.8
	P_{WL}	-0.2	-0.4	-0.2	0.5
Wave pressure for port side	P_{ctr}	0.5	0.3	0.5	0.5
	P_{bilge}	0.8	0.9	0.8	-0.3
	P_{WL}	0.5	0.7	0.5	-0.2

Note
Sagging bending moment is negative and hogging bending moment is positive

Table 7.6.e
Derivation of FE Dynamic Load Cases 6a and 6b

		Calculated (LCFs)		**FE Analysis (LCFs)**	
Wave direction		**Oblique (fully loaded)**	**Oblique (ballast)**	**Oblique**	
Rule Table		***Table 7.6.g***	***Table 7.6.h***	***Table 7.6.2 of the Rules***	
Max response		M_{wv-h}	M_{wv-h}	M_{wv-h}	M_{wv-h}
Reference Dynamic Load Case		**G***	**G***		
FE Dynamic Load Case				**6a**	**6b**
Hull girder	M_{wv}	0.2	0.4	0.4	0.4
	Q_{wv}	0.1	0.1	-0.1	-0.1
	M_{wv-h}	1.0	1.0	1.0	-1.0
Accelerations for tank pressure calculation	a_{v-mid}	0.1	-0.1	-0.1	-0.1
	$a_{v-ct-pt}$	0.1	-0.1	-0.1	-0.1
	$a_{v-ct-stb}$	0.1	-0.1	-0.1	-0.1
	a_t	0.0	0.0	0.0	0.0
	$a_{lng-mid}$	0.3	0.6	0.5	0.5
	$a_{lng-ct-pt}$	0.2	0.4	0.5	0.5
	$a_{lng-ct-stb}$	0.4	0.6	0.5	0.5
	$a_{lng-ctr}$	0.3	0.4	0.5	0.5
Wave pressure for starboard side	P_{ctr}	0.3	0.5	0.5	0.5
	P_{bilge}	0.1	0.0	0.0	0.4
	P_{WL}	0.1	0.0	0.0	0.6
Wave pressure for port side	P_{ctr}	0.3	0.5	0.5	0.5
	P_{bilge}	0.4	0.4	0.4	0.0
	P_{WL}	0.6	0.6	0.6	0.0

Notes:

1. * factor -1.0 applied to LCFs in *Tables 7.6.g and 7.6.h of the Rules* to obtain minimised cases
2. Sagging bending moment is negative and hogging bending moment is positive
3. longitudinal acceleration based on averaged values

6.4.2.k *FE Dynamic Load Cases 6a and 6b*: Maximum horizontal hull girder bending (oblique sea), see *Table 7.6.e*

- *FE Dynamic Load Cases 6a* and *6b* are oblique sea dynamic load cases with LCFs taken directly from the *Reference Dynamic Load Case G* in *Table 7.6.g* and *Table 7.6.h*.
- The load combination factors for the ballast condition (i.e. given in *Table 7.6.h*) are used as they are in general greater than the values obtained from the full load condition (i.e. given in *Table 7.6.g*).
- The LCFs for the vertical wave shear force is adjusted to zero to simplify the application of the procedure.

6.4.2.l The dynamic load cases maximising longitudinal acceleration (pitch) and the wave pressures in head sea (i.e. *Reference Dynamic Load Case D and F* in *Table 7.6.h* and *Table 7.6.h*) are covered by *FE Dynamic Load Cases 1 and 2* which give significantly greater hull girder loads and are therefore omitted. The dynamic load cases maximising vertical acceleration and wave pressure at beam seas (i.e. *Reference Dynamic Load Cases H, J and K* in *Table 7.6.h* and *Table 7.6.i*) are omitted as well since these cases are shown non-governing.

6.5 Dynamic Load Cases and Dynamic Load Combination for Scantling Requirements

6.5.1 General

6.5.1.a The EDW concept described in *6.3.1* is used to develop the dynamic load combination factors for scantling requirements.

6.5.1.b The dynamic load combination factors are found from analysis at four longitudinal positions along the ship as shown in *Figure 7.6.b* to ensure that the phasing differences along the hull are taken into account, in addition to the variation of the magnitude/importance of local dominance vs. global dominance.

6.5.1.c The factors for the stern region and the machinery space are extracted at a location between A.P. and the aft most cargo tank bulkhead.

6.5.1.d For the cargo region, except the foremost tank, the dynamic load combination factors are based on calculation at the tank amidships. Comparisons between aft most and amidships tank show that load combination factors for amidships give more conservative results. The longitudinal location is taken as the longitudinal centre of gravity of the hold in question.

6.5.1.e For the foremost tank the longitudinal position is located in the longitudinal centre of gravity of the tank.

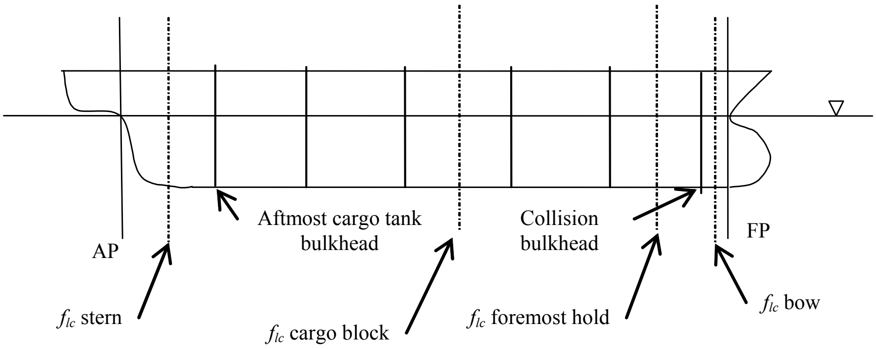
6.5.1.f The fore peak dynamic load combination factors are calculated between collision bulkhead and F.P.

6.5.1.g Since the calculation are also basis for the dynamic load combination factors for FE, the vertical shear force is extracted at the point where the greatest value of vertical wave shear force is obtained at a 10^{-8} probability level. These results are included in the tables for reference.

6.5.1.h Two different loading conditions are considered, namely the heavy ballast condition and the full load condition at scantling draught. The 3D hydro-dynamic analysis used as basis for the transfer-functions, are performed with zero forward speed.

6.5.1.i The dynamic load combinations factors are based on the average factors calculated for the ships investigated.

Figure 7.6.b
Longitudinal Positions For Evaluation Of Load Combination Factors



6.5.2 Dynamic load cases for midship and aft cargo region

6.5.2.a *Table 7.6.g* and *Table 7.6.h* give the results which form the basis for *Table 7.6.4* and *Table 7.6.5 of the Rules*.

6.5.2.b The EDW for full load and ballast condition yields similar results for vertical bending moment, vertical shear force and horizontal bending moment respectively. For local scantling assessment, the shear force has not been included in the rule-requirement, since the shear force effects are correctly assessed by the strength assessment by FE.

6.5.2.c It is assumed that the tank pressure can be described by maximising the three acceleration components individually for subsequently linear superposition to the total dynamic tank pressure. The wave headings investigated are generally the heading where the greatest response occurs. For vertical and transverse acceleration this is beam sea, while for longitudinal acceleration it is head sea. In addition the snapshot resulting from the EDW for vertical acceleration in head sea has been investigated, as the combination of tank pressure and hull-girder bending is critical.

Table 7.6.g
Load Combination Factor At Midship Hold For Full load Condition

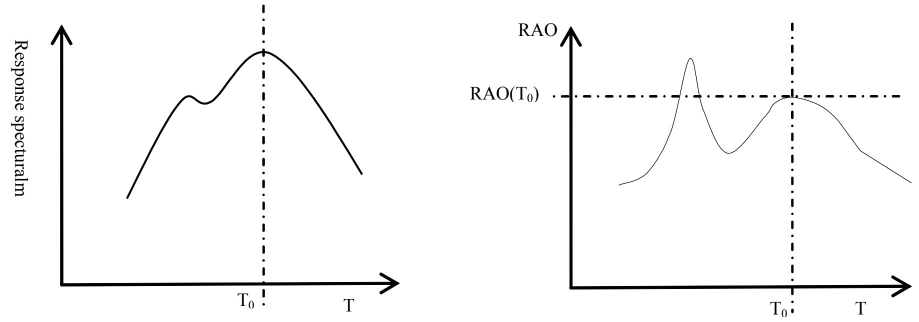
Maximised Secondary		Head Sea						Obl sea	Beam sea						
		M_{wv}	Q_{wv}	a_v	a_{lng}	P_{ctr}	P_{WL}	$M_{wv\text{-}h}$	$a_{v\text{-}mid}$	$a_{v\text{-}bt\text{-}stb}$	$a_{v\text{-}bt\text{-}pt}$	$a_{t\text{-}mid}$	$a_{t\text{-}bt\text{-}stb}$	P_{ctr}	P_{WL}
Hull girder	M_{wv}	1.0	-1.0	-1.0	0.5	0.7	0.8	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	-0.3
	Q_{wv}	-1.0	1.0	0.5		-0.3	-0.4	-0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1
	$M_{wv\text{-}h}$	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0
Dynamic Tank Pressure	$a_{v\text{-}mid}$	-0.2	0.3	0.5	-0.4	0.0	0.1	-0.1	1.0	1.0	0.9	0.5	0.5	1.0	1.0
	$a_{t\text{-}mid}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.6
	$a_{lng\text{-}mid}$	0.3	-0.6	-0.6	1.0	0.2	0.2	-0.3	-0.4	-0.5	-0.4	-0.1	-0.1	-0.5	-0.6
	$a_{v\text{-}ct\text{-}pt}$	-	-	-	-0.3	-	-	-0.1	0.8	0.8	0.8	0.2	0.2	0.8	0.8
	$a_{t\text{-}ct\text{-}pt}$	-	-	-	0.0	-	-	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.6
	$a_{lng\text{-}ct\text{-}pt}$	-	-	-	0.9	-	-	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1	-0.4	-0.5
	$a_{v\text{-}ct\text{-}stb}$	-	-	-	-0.3	-	-	-0.1	1.0	1.0	0.9	0.6	0.6	1.0	1.0
	$a_{t\text{-}ct\text{-}stb}$	-	-	-	0.0	-	-	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.6
	$a_{lng\text{-}ct\text{-}stb}$	-	-	-	0.9	-	-	-0.2	-0.4	-0.4	-0.4	-0.1	-0.1	-0.4	-0.5
	$a_{v\text{-}bt\text{-}pt}$	-	-	-	-0.2	-	-	-0.1	0.8	0.8	0.7	0.2	0.2	0.8	0.8
	$a_{t\text{-}bt\text{-}pt}$	-	-	-	0.0	-	-	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.6
	$a_{lng\text{-}bt\text{-}pt}$	-	-	-	0.9	-	-	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1	-0.4	-0.5
	$a_{v\text{-}bt\text{-}stb}$	-	-	-	-0.2	-	-	-0.1	1.0	1.0	0.9	0.7	0.7	1.0	1.0
	$a_{t\text{-}bt\text{-}stb}$	-	-	-	0.0	-	-	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.6
	$a_{lng\text{-}bt\text{-}stb}$	-	-	-	0.9	-	-	-0.1	-0.4	-0.4	-0.3	-0.1	-0.1	-0.4	-0.5
	$a_{v\text{-}ctr}$	-	-	-	-	-	-	-0.1	1.0	1.0	0.9	0.5	0.5	1.0	1.0
	$a_{t\text{-}ctr}$	-	-	-	-	-	-	0.0	0.5	0.5	0.5	1.0	1.0	0.5	0.7
	$a_{lng\text{-}ctr}$	-	-	-	-	-	-	-0.3	-0.5	-0.5	-0.4	-0.1	-0.1	-0.5	-0.6
Port side wave pressure	P_{ctr}	0.7	0.2	-0.6	0.2	0.6	0.9	-0.3	0.9	0.9	0.9	0.4	0.4	0.9	0.9
	$P_{B/4}$	0.5	0.2	-0.4	0.1	0.5	0.7	-0.2	0.7	0.7	0.6	0.1	0.1	0.7	0.7
	P_{bilge}	0.3	0.1	-0.2	0.1	0.3	0.5	-0.1	0.4	0.4	0.4	-0.3	-0.3	0.4	0.4
	$P_{B/2\text{-}T/2}$	0.3	0.1	-0.3	0.1	0.3	0.5	-0.1	0.4	0.4	0.4	-0.3	-0.3	0.4	0.4
	P_{WL}	0.3	0.1	-0.3	0.1	0.3	0.5	-0.1	0.4	0.4	0.3	-0.2	-0.2	0.4	0.4
Starboard wave pressure	P_{ctr}	0.7	0.2	-0.6	0.2	0.6	0.9	-0.3	1.0	1.0	0.9	0.6	0.6	1.0	0.9
	$P_{B/4}$	0.5	0.2	-0.4	0.1	0.5	0.7	-0.4	1.0	1.0	0.9	0.7	0.7	1.0	1.0
	P_{bilge}	0.3	0.1	-0.2	0.1	0.3	0.5	-0.4	0.9	0.9	0.9	0.8	0.8	0.9	1.0
	$P_{B/2\text{-}T/2}$	0.3	0.1	-0.3	0.1	0.3	0.5	-0.5	0.9	0.9	0.8	0.7	0.7	0.9	1.0
	P_{WL}	0.3	0.1	-0.3	0.1	0.3	0.5	-0.6	0.8	0.8	0.7	0.5	0.5	0.8	1.0
	θ	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.2	1.0	1.0	0.3	0.2
	ϕ	-0.1	0.4	0.5	-0.6	0.0	-0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2
Resulting Dynamic load case no for scantling requirement		**1**	**Not applicable**	**2**	**3**	**(2)**	**not governing**	**4a and 4b**	**6a and 6b**			**5a and 5b**		**7a and 7b**	**8a and 8b**
Reference Dynamic Load Case (for FE)		**A**	**B**	**C**	**D**	**(C)**	**E**	**F**	**G**			**H**		**I**	**J**

Table 7.6.h
Load Combination Factor At Midship Hold For Ballast Condition

Maximised / Secondary		Head Sea						Obl sea	Beam sea						
		M_{wv}	Q_{wv}	a_v	a_{lng}	P_{ctr}	P_{WL}	$M_{wv\text{-}h}$	$a_{v\text{-}mid}$	$a_{v\text{-}bt\text{-}stb}$	$a_{v\text{-}bt\text{-}pt}$	$a_{t\text{-}mid}$	$a_{t\text{-}bt\text{-}stb}$	P_{ctr}	P_{WL}
Hull girder	M_{wv}	1.0	-1.0	-1.0	0.4	0.8	0.4	-0.4	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2
	Q_{wv}	-0.9	1.0	0.3		0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	$M_{wv\text{-}h}$	0.0	0.0	0.0	0.0	0.0	0.0	1.0	-0.2	-0.1	-0.2	0.1	0.1	-0.1	-0.2
Dynamic Tank Pressure	$a_{v\text{-}mid}$	-0.1	0.2	0.4	-0.2	0.0	0.2	0.1	1.0	0.8	0.9	0.5	0.5	1.0	1.0
	$a_{t\text{-}mid}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.4	1.0	1.0	0.8	0.6
	$a_{lng\text{-}mid}$	0.2	-0.3	-0.1	1.0	0.1	-0.5	-0.6	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
	$a_{v\text{-}ct\text{-}pt}$				-0.1			0.1	0.6	0.4	0.6	0.1	0.1	0.8	0.7
	$a_{t\text{-}ct\text{-}pt}$				0.0			0.0	0.5	0.7	0.5	1.0	1.0	0.6	0.6
	$a_{lng\text{-}ct\text{-}pt}$				1.0			-0.6	-0.1	-0.1	-0.1	0.0	0.0	-0.2	-0.1
	$a_{v\text{-}ct\text{-}stb}$				-0.1			0.1	0.9	1.0	0.9	0.7	0.7	1.0	1.0
	$a_{t\text{-}ct\text{-}stb}$				0.0			0.0	0.5	0.7	0.5	1.0	1.0	0.6	0.6
	$a_{lng\text{-}ct\text{-}stb}$				1.0			-0.4	-0.1	-0.1	-0.1	0.0	0.0	-0.2	-0.1
	$a_{v\text{-}bt\text{-}pt}$				-0.1			0.1	0.5	0.4	0.5	-0.1	-0.1	0.7	0.6
	$a_{t\text{-}bt\text{-}pt}$				0.0			0.0	0.5	0.7	0.5	1.0	1.0	0.6	0.6
	$a_{lng\text{-}bt\text{-}pt}$				1.0			-0.6	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1
	$a_{v\text{-}bt\text{-}stb}$				-0.1			0.1	0.9	1.0	0.9	0.8	0.8	1.0	1.0
	$a_{t\text{-}bt\text{-}stb}$				0.0			0.0	0.5	0.7	0.5	1.0	1.0	0.6	0.6
	$a_{lng\text{-}bt\text{-}stb}$				1.0			-0.4	-0.1	-0.1	-0.1	0.0	0.0	-0.2	-0.1
	$a_{v\text{-}ctr}$							0.1	1.0	0.9	0.9	0.6	0.6	1.0	1.0
	$a_{t\text{-}ctr}$							0.0	0.5	0.7	0.5	1.0	1.0	0.6	0.7
	$a_{lng\text{-}ctr}$							-0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.3	-0.2
Port side wave pressure	P_{ctr}	1.0	0.3	-0.8	0.3	1.0	0.9	-0.5	0.3	0.4	0.3	0.2	0.2	0.7	0.3
	$P_{B/4}$	0.7	0.2	-0.5	0.2	0.7	0.7	-0.2	0.2	-0.2	0.2	-0.1	-0.1	0.4	0.2
	P_{bilge}	0.3	0.1	-0.2	0.1	0.4	0.5	0.0	0.2	-0.4	0.2	-0.4	-0.4	0.3	0.2
	$P_{B/2\text{-}T/2}$	0.3	0.1	-0.2	0.1	0.4	0.5	0.0	0.2	-0.3	0.2	-0.4	-0.4	0.2	0.2
	P_{WL}	0.3	0.1	-0.2	0.1	0.4	0.5	0.0	0.2	-0.3	0.2	-0.4	-0.4	0.2	0.2
Starboard wave pressure	P_{ctr}	1.0	0.3	-0.8	0.3	1.0	0.9	-0.5	0.4	0.5	0.3	0.4	0.4	0.8	0.4
	$P_{B/4}$	0.7	0.2	-0.5	0.2	0.7	0.7	-0.5	0.6	0.7	0.5	0.7	0.7	0.9	0.7
	P_{bilge}	0.3	0.1	-0.2	0.1	0.4	0.5	-0.4	0.8	0.9	0.7	0.9	0.9	0.9	0.9
	$P_{B/2\text{-}T/2}$	0.3	0.1	-0.2	0.1	0.4	0.5	-0.5	0.8	0.9	0.8	0.8	0.8	0.9	1.0
	P_{WL}	0.3	0.1	-0.2	0.1	0.4	0.5	-0.6	0.8	0.8	0.8	0.7	0.7	0.9	1.0
	θ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.2	0.9	0.9	0.4	0.3
	ϕ	-0.2	0.3	0.1	-0.8	-0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Resulting Dynamic load case no for scantling requirement		**1**	**Not governing**	**2**	**3**	**2**	**Not governing**	**4a and 4b**	**6a and 6b**	**5a and 5b**	**6a and 6b**	**5a and 5b**		**7a and 7b**	**8a and 8b**
Reference Dynamic Load Case (for FE)		**A**	**B**	**C**	**D**	**C**	**D**	**E**	**F**	**G**	**F**	**H**		**I**	**J**

6.5.2.d In head sea the vertical acceleration transfer-function is two peaked, see *Figure 7.6.c.* The wave spectra contributions to the long term response has been investigated, concluding that the highest peak occurs at a wave periods outside the energy contribution range; hence the second peak have been chosen for further investigation. The maximised head sea vertical acceleration is similar to that of maximised vertical bending moment.

Figure 7.6.c
Transfer Function and Response Spectrum of Vertical Acceleration in Head Sea



The second peak of the transfer function gives a larger contribution to the envelope value at 10^{-8} probability level than the greatest peak, as seen from the response spectrum curve

6.5.2.e The vertical acceleration in beam sea is maximized at centre-line and at the port and starboard side. For full load condition these three locations give the same design wave and load combination factors. For ballast condition, the results vary with ship size. While the smaller ships have the same EDW for all three locations, the larger ships have the same EDW at centreline and on the lee side, while the weather side follows the EDW of the transverse acceleration.

6.5.2.f The vertical acceleration response is closely linked to the heave motion. It can also be influenced by roll motion, which is the case when the roll natural period falls close to the heave natural period. In such cases, as observed for the largest ships, the roll dominance is seen on weather side. This is most pronounced for ballast condition since the motions are higher.

6.5.2.g The similarities of the three a_v beam sea dynamic load cases justified merging them into one dynamic load case for vertical acceleration in beam sea.

6.5.2.h The transverse acceleration is maximized in centre-tank and on weather side. Both locations result in the same EDW and dynamic load combination factors. All ships show similar behaviour in terms of maximum roll angle and negligible pitch angle in both loading conditions. The two dynamic load cases are merged into one dynamic load case for transverse acceleration.

6.5.2.i The wave pressure was investigated for four EDW which maximized the centreline and the waterline wave pressure in head sea and beam sea.

6.5.2.j For the full load condition in beam sea, the centreline wave pressure EDW equals the vertical acceleration dynamic load case in beam sea. The waterline wave pressure has a similar design wave, but with slightly higher tank pressures.

6.5.2.k For the ballast condition, the centreline long term pressure has its maximum in head sea instead of beam sea. The differences between the EDW for the centreline wave pressure and the vertical acceleration dynamic load cases are larger than for the full load condition. The maximized beam sea waterline pressure shows similarities with the beam sea vertical acceleration load as is also observed for full load condition.

6.5.3 Dynamic load cases for forward cargo region

6.5.3.a *Table 7.6.i* and *Table 7.6.j* give the results which form the basis for *Table 7.6.6* and *Table 7.6.7 of the Rules*.

6.5.3.b In forward cargo tank region, maximizing hull girder loads is not necessary since they are smaller in this region, whilst the local loads are increasing. The hull-girder loads are only included as secondary responses.

6.5.3.c The tank pressures are maximized in the wave heading with the highest long term response, which is head sea for longitudinal acceleration and beam sea for vertical and transverse acceleration. The vertical acceleration is also maximized in head sea to capture the combined effect with longitudinal acceleration and hull girder loads.

6.5.3.d The vertical acceleration RAO in head sea is two-peaked. The wave energy contribution on short term responses has been considered when developing dynamic load combination factors for the vertical acceleration in head sea, see *6.3.1.d*. The three dynamic load cases investigated for vertical acceleration are merged into one dynamic load case.

Table 7.6.i
Dynamic Load Combination Factor At Foremost Hold For Full load Condition

Maximised / Secondary		Head sea		Oblique sea					Beam sea					
		a_v	a_{lng}	$a_{lng\text{-}ct\text{-}stb}$	$a_{lng\text{-}bt\text{-}stb}$	P_{ctr}	P_{bilge}	P_{WL}	$a_{v\text{-}mid}$	$a_{v\text{-}ct\text{-}stb}$	$a_{v\text{-}bt\text{-}stb}$	$a_{t\text{-}mid}$	$a_{t\text{-}ct\text{-}stb}$	$a_{t\text{-}bt\text{-}stb}$
Hull girder	M_{wv}	-0.7	1.0	0.3	0.3	-0.6	-0.3	-0.4	-0.4	-0.3	-0.3	-0.2	-0.1	-0.1
	$M_{wv\text{-}h}$	0.0	0.0	-0.2	-0.2	0.2	-0.1	0.2	-0.1	-0.1	-0.1	-0.2	-0.5	-0.5
Tank pressure	$a_{v\text{-}mid}$	0.7	-0.6	-0.5	-0.5	0.7	0.9	0.7	1.0	0.9	0.9	0.4	0.4	0.4
	$a_{t\text{-}mid}$	0.0	0.0	0.4	0.4	0.1	0.7	0.5	0.8	0.7	0.7	1.0	1.0	1.0
	$a_{lng\text{-}mid}$	-1.0	1.0	0.8	0.8	-1.0	-0.6	-1.0	-0.6	-0.6	-0.6	-0.2	-0.2	-0.2
	$a_{v\text{-}ct\text{-}pt}$	-	-0.6	-0.6	-0.5	0.7	0.9	0.7	0.9	0.9	0.8	0.3	0.3	0.3
	$a_{t\text{-}ct\text{-}pt}$	-	0.0	0.4	0.4	0.1	0.7	0.5	0.8	0.6	0.6	**1.0**	1.0	1.0
	$a_{lng\text{-}ct\text{-}pt}$	-	0.9	0.6	0.6	-1.0	-0.6	-1.0	-0.6	-0.5	-0.5	-0.2	-0.1	-0.1
	$a_{v\text{-}ct\text{-}stb}$	0.7	-0.6	-0.6	-0.5	0.7	1.0	0.6	**1.1**	1.0	1.0	0.6	0.6	0.6
	$a_{t\text{-}ct\text{-}stb}$	0.0	0.0	0.4	0.4	0.1	0.7	0.5	0.8	0.6	0.6	**1.0**	1.0	1.0
	$a_{lng\text{-}ct\text{-}stb}$	-0.8	0.9	1.0	1.0	-0.9	-0.5	-0.7	-0.6	-0.5	-0.5	-0.1	-0.1	-0.1
	$a_{v\text{-}bt\text{-}pt}$	-	-0.6	-0.6	-0.5	0.7	0.8	0.6	0.8	0.8	0.8	0.2	0.3	0.3
	$a_{t\text{-}bt\text{-}pt}$	-	0.0	0.4	0.4	0.1	0.7	0.5	0.8	0.6	0.6	1.0	1.0	1.0
	$a_{lng\text{-}bt\text{-}pt}$	-	1.0	0.4	0.4	-1.0	-0.6	-1.0	-0.6	-0.5	-0.5	-0.2	-0.1	-0.2
	$a_{v\text{-}bt\text{-}stb}$	0.7	-0.6	-0.6	-0.5	0.7	1.0	0.6	**1.1**	1.0	1.0	0.6	0.6	0.6
	$a_{t\text{-}bt\text{-}stb}$	0.0	0.0	0.4	0.4	0.1	0.7	0.5	0.8	0.6	0.6	1.0	1.0	1.0
	$a_{lng\text{-}bt\text{-}stb}$	-0.8	1.0	1.0	1.0	-0.8	-0.5	-0.5	-0.6	-0.5	-0.5	-0.1	-0.1	-0.1
Portside wave pressure	P_{ctr}	-	-0.9	-0.4	-0.4	1.0	0.8	0.5	0.9	0.8	0.8	0.4	0.4	0.4
	$P_{B/4}$	-	-0.7	-0.5	-0.5	0.8	0.6	0.4	0.6	0.6	0.6	0.1	0.1	0.1
	P_{bilge}	-	-0.6	-0.6	-0.6	0.6	0.5	0.3	0.5	0.5	0.5	-0.1	-0.1	-0.1
	$P_{B/2\text{-}T/2}$	-	-0.6	-0.8	-0.7	0.5	0.5	0.2	0.5	0.5	0.5	-0.1	-0.2	-0.2
	P_{WL}	-	-0.5	-0.9	-0.8	0.4	0.4	0.2	0.4	0.4	0.4	-0.1	-0.2	-0.2
Starboard side wave pressure	P_{ctr}	1.0	-0.9	-0.4	-0.4	1.0	0.8	0.5	0.9	0.8	0.8	0.5	0.5	0.5
	$P_{B/4}$	0.9	-0.7	-0.3	-0.3	0.9	0.9	0.6	**1.0**	0.9	0.9	0.7	0.7	0.7
	P_{bilge}	0.6	-0.6	-0.2	-0.2	0.9	1.0	0.7	**1.1**	1.0	1.0	0.7	0.8	0.8
	$P_{B/2\text{-}T/2}$	0.5	-0.6	-0.2	-0.2	0.8	1.0	0.9	**1.1**	1.0	1.0	0.7	0.7	0.7
	P_{WL}	0.3	-0.5	-0.2	-0.2	0.8	0.9	1.0	1.0	0.9	0.9	0.5	0.6	0.6
Motion	θ	0.0	0.0	0.0	0.0	-0.1	0.4	0.0	0.5	0.4	0.4	**1.0**	1.0	1.0
	ϕ	1.0	-0.6	-0.5	-0.5	0.7	0.3	0.6	0.3	0.3	0.3	0.1	0.1	0.1
Resulting Dynamic load case no for scantling requirement		**1**	**2**	**3a and 3b**		**4a and 4b**	**5a and 5b**	**6a and 6b**	**7a and 7b**			**8a and 8b**		

Table 7.6.j
Dynamic Load Combination Factor At Foremost Hold For Ballast Condition

Secondary \ Maximised		Head sea		Oblique sea					Beam sea					
		a_v	a_{lng}	$a_{lng\text{-}ct\text{-}stb}$	$a_{lng\text{-}bt\text{-}stb}$	P_{ctr}	P_{bilge}	P_{WL}	$a_{v\text{-}mid}$	$a_{v\text{-}ct\text{-}stb}$	$a_{v\text{-}bt\text{-}stb}$	$a_{t\text{-}mid}$	$a_{t\text{-}ct\text{-}stb}$	$a_{t\text{-}bt\text{-}stb}$
Hull girder	M_{wv}	-0.8	0.9	0.7	0.8	-1.0	-0.2	-0.3	0.0	-0.1	-0.1	0.0	-0.1	-0.1
	$M_{wv\text{-}h}$	0.0	0.0	0.4	0.3	0.0	-0.5	0.3	-0.5	-0.4	-0.4	-0.7	-0.4	-0.4
Tank pressure	$a_{v\text{-}mid}$	0.8	-0.6	-0.7	-0.7	0.5	0.6	0.9	1.0	0.9	0.9	0.4	0.4	0.4
	$a_{t\text{-}mid}$	0.0	0.0	0.0	0.0	0.0	1.0	0.2	0.8	0.7	0.8	1.0	1.0	1.0
	$a_{lng\text{-}mid}$	-1.0	1.0	1.0	1.0	-0.6	-0.3	-1.0	-0.1	-0.1	-0.1	0.0	0.0	0.0
	$a_{v\text{-}ct\text{-}pt}$	-	-0.5	-0.7	-0.7	0.4	0.4	0.7	0.6	0.6	0.6	0.0	0.1	0.1
	$a_{t\text{-}ct\text{-}pt}$	-	0.0	0.0	0.1	0.0	0.9	0.1	0.8	0.7	0.7	**1.0**	1.0	1.0
	$a_{lng\text{-}ct\text{-}pt}$	-	1.0	1.0	0.9	-0.6	-0.4	-0.9	-0.1	0.0	0.0	0.0	0.1	0.1
	$a_{v\text{-}ct\text{-}stb}$	0.7	-0.5	-0.7	-0.7	0.4	0.8	0.7	**1.1**	1.0	1.0	0.7	0.7	0.7
	$a_{t\text{-}ct\text{-}stb}$	0.0	0.0	0.0	0.1	0.0	0.9	0.1	0.8	0.7	0.7	**1.0**	1.0	1.0
	$a_{lng\text{-}ct\text{-}stb}$	-0.9	1.0	1.0	1.0	-0.6	-0.2	-0.7	-0.1	0.0	0.0	0.0	0.0	0.0
	$a_{v\text{-}bt\text{-}pt}$	-	-0.5	-0.7	-0.7	0.4	0.3	0.7	0.5	0.5	0.5	0.0	0.0	0.0
	$a_{t\text{-}bt\text{-}pt}$	-	0.0	0.0	0.1	0.0	0.9	0.2	0.8	0.7	0.7	1.0	1.0	1.0
	$a_{lng\text{-}bt\text{-}pt}$	-	1.0	0.9	0.9	-0.6	-0.5	-0.9	-0.1	-0.1	-0.1	0.0	0.1	0.1
	$a_{v\text{-}bt\text{-}stb}$	0.7	-0.5	-0.7	-0.7	0.4	0.8	0.7	**1.1**	1.0	1.0	0.7	0.7	0.7
	$a_{t\text{-}bt\text{-}stb}$	0.0	0.0	0.0	0.1	0.0	0.9	0.2	0.8	0.7	0.7	1.0	1.0	1.0
	$a_{lng\text{-}bt\text{-}stb}$	-0.8	1.0	1.0	1.0	-0.6	0.2	-0.6	0.0	0.0	0.0	0.0	0.1	0.1
Portside wave pressure	P_{ctr}	-	-0.7	-0.9	-0.9	1.0	0.5	0.6	0.6	0.4	0.4	0.2	0.2	0.2
	$P_{B/4}$	-	-0.6	-0.9	-0.9	0.8	0.1	0.3	0.3	0.2	0.2	-0.2	-0.2	-0.2
	P_{bilge}	-	-0.4	-0.7	-0.8	0.6	-0.3	0.2	0.2	0.2	0.2	-0.3	-0.3	-0.4
	$P_{B/2\text{-}T/2}$	-	-0.2	-0.7	-0.7	0.4	-0.3	0.2	0.2	0.2	0.2	-0.4	-0.4	-0.4
	P_{WL}	-	-0.2	-0.6	-0.7	0.4	-0.3	0.1	0.1	0.2	0.2	-0.3	-0.4	-0.4
Starboard side wave pressure	P_{ctr}	1.0	-0.7	-0.9	-0.9	1.0	0.7	0.6	0.6	0.5	0.5	0.3	0.3	0.3
	$P_{B/4}$	0.8	-0.6	-0.6	-0.7	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6
	P_{bilge}	0.5	-0.4	-0.3	-0.4	0.6	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7
	$P_{B/2\text{-}T/2}$	0.4	-0.2	-0.2	-0.2	0.4	1.0	0.9	1.0	0.9	0.9	0.8	0.7	0.8
	P_{WL}	0.3	-0.2	-0.1	-0.1	0.4	0.9	1.0	0.9	0.8	0.8	0.7	0.7	0.7
Motion	θ	0.0	0.0	0.0	0.1	0.0	0.8	0.0	0.5	0.5	0.5	0.9	0.9	1.0
	ϕ	1.0	-0.7	-0.8	-0.8	0.5	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Resulting Dynamic load case no for scantling requirement		**1**	**2**	**3a and 3b**		**4a and 4b**	**5a and 5b**	**6a and 6b**	**7a and 7b**			**8a and 8b**		

6.5.3.e The three dynamic load cases maximising transverse acceleration give similar EDW values, and are therefore merged into one dynamic load case.

6.5.3.f The longitudinal acceleration is maximized at three locations, resulting in two dynamic load cases; one for oblique and one for head sea. For the longitudinal acceleration in centre cargo tank, head sea is dominating. For the wing cargo and ballast tanks, oblique sea is governing.

6.5.3.g The wing cargo and ballast tanks have the same EDW and dynamic load combination factors.

6.5.3.h For the centre ballast tank in foremost hold, the vertical and longitudinal acceleration load combination factors can be taken equal to the load combination factors at 'mid' location. This is justified by the vertical acceleration being constant with height in the cross section, confirmed by calculations at midship.

6.5.3.i There are three wave pressure EDW maximizing the centreline, bilge and waterline wave pressure. The wave direction with the highest long term response value is chosen as the design wave heading. Beam/oblique sea is the governing wave direction, with exception for the EDW for the wave pressure at centreline for the ballast condition, which is larger for head sea. But since the long term response in beam/oblique sea shows insignificant change between the 90° and 120°/150° wave directions, the wave headings are unified. It was verified that the three locations at EDW cover the most onerous combination of dynamic loads, by adding two more EDW representing the wave pressure between centreline and bilge and between bilge and waterline. For full load condition, the EDW for $P_{B/2-T/2}$ equals the EDW for P_{bilge}, and the EDW for $P_{B/4}$, equal the EDW for P_{WL} and P_{ctr}. For ballast condition the two new wave pressure dynamic load cases, $P_{B/4}$ and $P_{B/2-T/2}$, are very similar to the maximized P_{bilge} dynamic load case.

6.5.4 Dynamic load cases for area outside the cargo tank region

6.5.4.a *Table 7.6.k* to *Table 7.6.l* give the results which form the basis for the dynamic load cases as given in *Table 7.6.8* and *Table 7.6.9 of the Rules*.

(a) The vertical wave bending moment is maximized at the aftmost cargo tank bulkhead to cover the engine room area. In the stern region the largest long term value occurs in following sea. This dynamic load case was omitted in the final table as it was shown to be non-governing.

(b) The tank pressures are maximized in the wave heading with the largest long term response, which is beam sea for vertical and transverse acceleration.

(c) The vertical acceleration is maximized at two locations, denoted 'mid' and 'side shell'. They result in similar dynamic load combination factors and design wave, which justifies merging them into one dynamic load case.

(d) The transverse acceleration is maximized at three locations in the cross section, denoted 'mid', 'side shell' and 'deck house'. The locations "mid" and "side shell" result in identical load combination factors and design wave, at deck house top shows similarities. The three a_t dynamic load cases in beam sea are merged into one beam sea dynamic load case for transverse acceleration.

(e) There are two EDW maximizing wave pressure, one at centre line and one at the still waterline. The wave direction with the largest long term response is chosen as the design wave heading. Oblique sea is governing for the wave pressure at water line while the largest long term response for the bottom pressure occurs in following sea.

Table 7.6.k
Load Combination Factor For Stern Region For Full load Condition

Maximised **Secondary**		**Following sea**		**Oblique**	**Beam sea**				
		M_{wv}	P_{ctr}	P_{WL}	a_{v-mid}	a_{v-ss}	a_{t-mid}	a_{t-ss}	$a_{t- house}$
Hull girder	M_{wv}	1.0	-1.0	-0.7	-0.4	-0.4	-0.1	-0.1	-0.1
Tank pressure	a_{v-mid}	-0.4	0.6	0.9	1.0	1.0	0.3	0.3	0.3
	a_{t-mid}	0.0	0.0	0.2	0.5	0.5	1.0	1.0	0.9
	$a_{lng-mid}$	-0.6	0.8	0.7	0.5	0.5	-0.1	-0.1	-0.1
	a_{v-ss}	-0.4	0.6	0.9	1.0	1.0	0.4	0.4	0.4
	a_{t-ss}	0.0	0.0	0.2	0.5	0.5	1.0	1.0	0.9
	a_{lng-ss}	-0.6	0.7	0.6	0.5	0.4	-0.1	-0.1	-0.1
	$a_{v-house}$	-0.4	0.6	0.9	1.0	1.0	0.3	0.3	0.3
	$a_{t-house}$	0.0	0.0	0.2	0.5	0.5	1.0	1.0	1.0
	$a_{lng-house}$	-0.6	0.7	0.8	0.6	0.6	-0.1	-0.1	-0.1
Port side wave pressure	P_{ctr}	-0.8	1.0	0.8	0.7	0.7	0.2	0.2	0.2
	P_{WL}	-0.5	0.5	0.2	0.3	0.3	-0.3	-0.3	-0.3
Starboard wave pressure	P_{ctr}	-0.8	1.0	0.8	0.7	0.7	0.3	0.3	0.3
	P_{WL}	-0.5	0.5	1.0	0.8	0.8	0.5	0.5	0.4
Motions	θ	0.0	0.0	0.1	0.1	0.1	1.0	1.0	1.0
	ϕ	0.5	-0.8	-0.5	-0.4	-0.3	0.1	0.1	0.0
Resulting Dynamic load case no for scantling requirement		**Not governing**	**1**	**2a and 2b**	**3a and 3b**		**4a and 4b**		

Table 7.6.l
Load Combination Factor For Stern Region For Ballast Condition

Secondary \ Maximised		Following sea		Oblique	Beam sea				
		M_{wv}	P_{ctr}	P_{WL}	a_{v-mid}	a_{v-ss}	a_{t-mid}	a_{t-ss}	$a_{t-house}$
Hull girder	M_{wv}	1.0	-1.0	-0.3	0.2	0.2	0.1	0.1	0.1
Tank pressure	a_{v-mid}	-0.4	0.6	0.9	1.0	0.9	0.3	0.3	0.3
	a_{t-mid}	0.0	0.0	0.1	0.6	0.6	1.0	1.0	0.9
	$a_{lng-mid}$	-0.5	0.7	0.8	0.1	0.1	0.0	0.0	0.0
	a_{v-ss}	-0.3	0.5	0.9	1.0	1.0	0.5	0.5	0.5
	a_{t-ss}	0.0	0.0	0.1	0.6	0.6	1.0	1.0	0.9
	a_{lng-ss}	-0.5	0.7	0.7	0.1	0.1	0.0	0.0	0.0
	$a_{v-house}$	-0.4	0.6	0.9	1.0	0.9	0.3	0.3	0.3
	$a_{t-house}$	0.0	0.0	0.1	0.6	0.6	1.0	1.0	1.0
	$a_{lng-house}$	-0.4	0.7	0.9	0.2	0.2	0.0	0.0	0.0
Port side wave pressure	P_{ctr}	-0.8	1.0	0.7	0.5	0.5	0.1	0.1	0.1
	P_{WL}	-0.7	0.8	0.3	0.1	0.1	-0.3	-0.3	-0.3
Starboard wave pressure	P_{ctr}	-0.8	1.0	0.7	0.5	0.5	0.2	0.2	0.2
	P_{WL}	-0.7	0.8	1.0	0.6	0.6	0.4	0.4	0.4
Motions	θ	0.0	0.0	0.0	0.3	0.3	1.0	1.0	0.9
	ϕ	0.4	-0.6	-0.5	-0.1	-0.1	0.0	0.0	0.0
Resulting Dynamic load case no for scantling requirement		**Not governing**	**1**	**2a and 2b**	**3a and 3b**		**4a and 4b**		

6.5.4.b *Table 7.6.m* and *Table 7.6.n* give the results which form the basis for the fore peak part in *Table 7.6.8* and *Table 7.6.9 of the Rules*.

(a) There are two wave pressure EDW, maximizing the wave pressure at centreline and waterline. The wave direction with the largest long term response is chosen as the design wave heading. Oblique sea is governing for the water line pressure while the largest long term response for wave pressure at centreline occurs in following sea. These two load cases are shown to be non-governing and are therefore omitted from the tables of the Rules.

(b) The vertical acceleration is maximized at two locations in the cross section, denoted 'mid' and 'side shell'. The similarities of the two a_v EDWs in beam sea justifies merging them into one dynamic load case.

(c) The transverse acceleration is maximized at two locations in the cross section, denoted 'mid' and 'side shell'. They result in identical load combination factors and design wave.

Table 7.6.m
Load Combination Factor For Fore Peak For Full load Condition

		Head sea	Oblique sea	Beam sea			
		P_{ctr}	P_{WL}	a_{v-mid}	a_{v-ss}	a_{t-mid}	a_{t-ss}
Tank pressure	a_{v-mid}	0.6	0.7	1.0	1.0	0.3	0.3
	a_{t-mid}	0.0	0.2	0.7	0.6	1.0	1.0
	$a_{lng-mid}$	-0.9	-1.0	-0.7	-0.7	-0.1	-0.1
	a_{v-ss}	0.6	0.7	1.0	1.0	0.3	0.3
	a_{t-ss}	0.0	0.2	0.7	0.6	1.0	1.0
	a_{lng-ss}	-0.9	-0.9	-0.7	-0.6	-0.1	-0.1
Port side wave pressure	P_{ctr}	1.0	0.9	0.8	0.8	0.2	0.2
	P_{WL}	0.9	0.9	0.6	0.6	0.0	0.0
Starboard wave pressure	P_{ctr}	1.0	0.9	0.8	0.8	0.2	0.2
	P_{WL}	0.9	1.0	0.8	0.8	0.2	0.2
Motions	θ	0.0	0.1	0.3	0.3	1.0	1.0
	ϕ	0.6	0.6	0.3	0.3	0.1	0.1
Resulting Dynamic load case no for scantling requirement		**Not governing**	**Not governing**	**5a and 5b**		**6a and 6b**	

Table 7.6.n
Load Combination Factor For Fore Peak For Ballast Condition

		Head sea	Oblique sea	Beam sea			
		P_{ctr}	P_{WL}	a_{v-mid}	a_{v-ss}	a_{t-mid}	a_{t-ss}
Tank pressure	a_{v-mid}	0.6	0.7	1.0	0.9	0.3	0.3
	a_{t-mid}	0.0	0.1	0.7	0.7	1.0	1.0
	$a_{lng-mid}$	-0.9	-1.0	-0.3	-0.3	0.0	0.0
	a_{v-ss}	0.5	0.7	1.0	1.0	0.5	0.5
	a_{t-ss}	0.0	0.1	0.7	0.7	1.0	1.0
	a_{lng-ss}	-0.8	-1.0	-0.3	-0.3	0.0	0.0
Port side wave pressure	P_{ctr}	1.0	0.9	0.5	0.5	0.1	0.1
	P_{WL}	0.8	0.7	0.3	0.3	-0.1	-0.1
Starboard wave pressure	P_{ctr}	1.0	0.9	0.6	0.6	0.2	0.2
	P_{WL}	0.8	1.0	0.7	0.6	0.3	0.3
Motions	θ	0.0	0.1	0.3	0.3	1.0	1.0
	ϕ	0.6	0.5	0.1	0.1	0.0	0.0
Resulting Dynamic load case no for scantling requirement		**Not governing**	**Not governing**	**5a and 5b**		**6a and 6b**	